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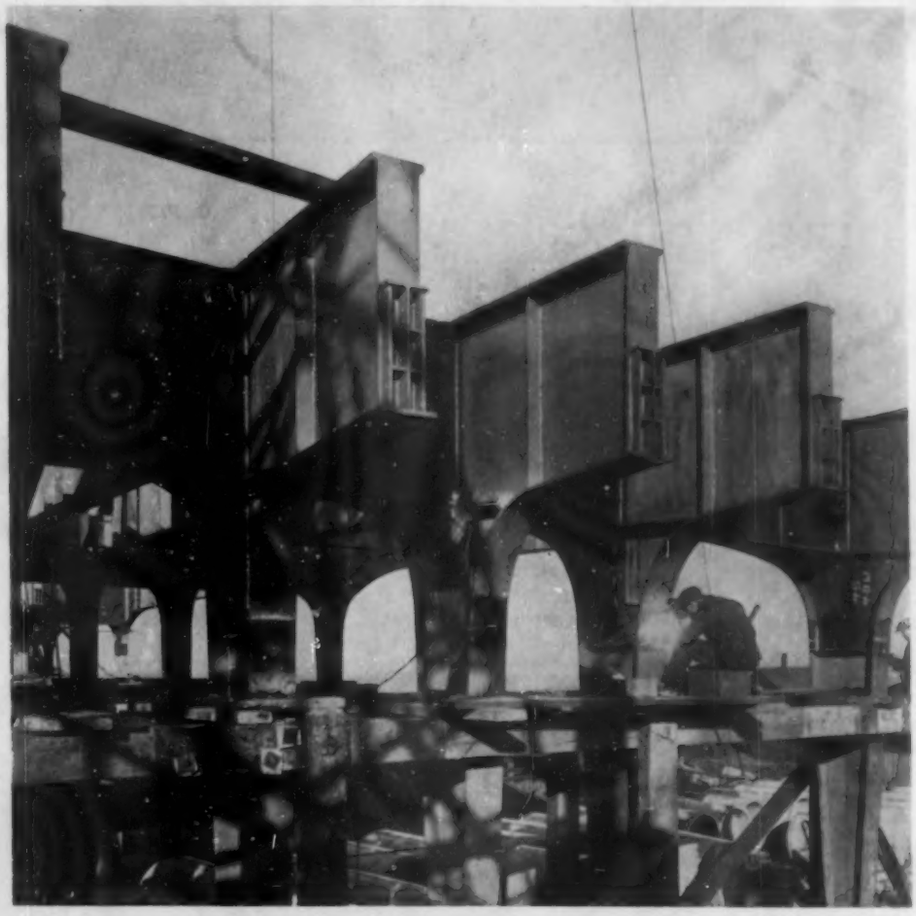
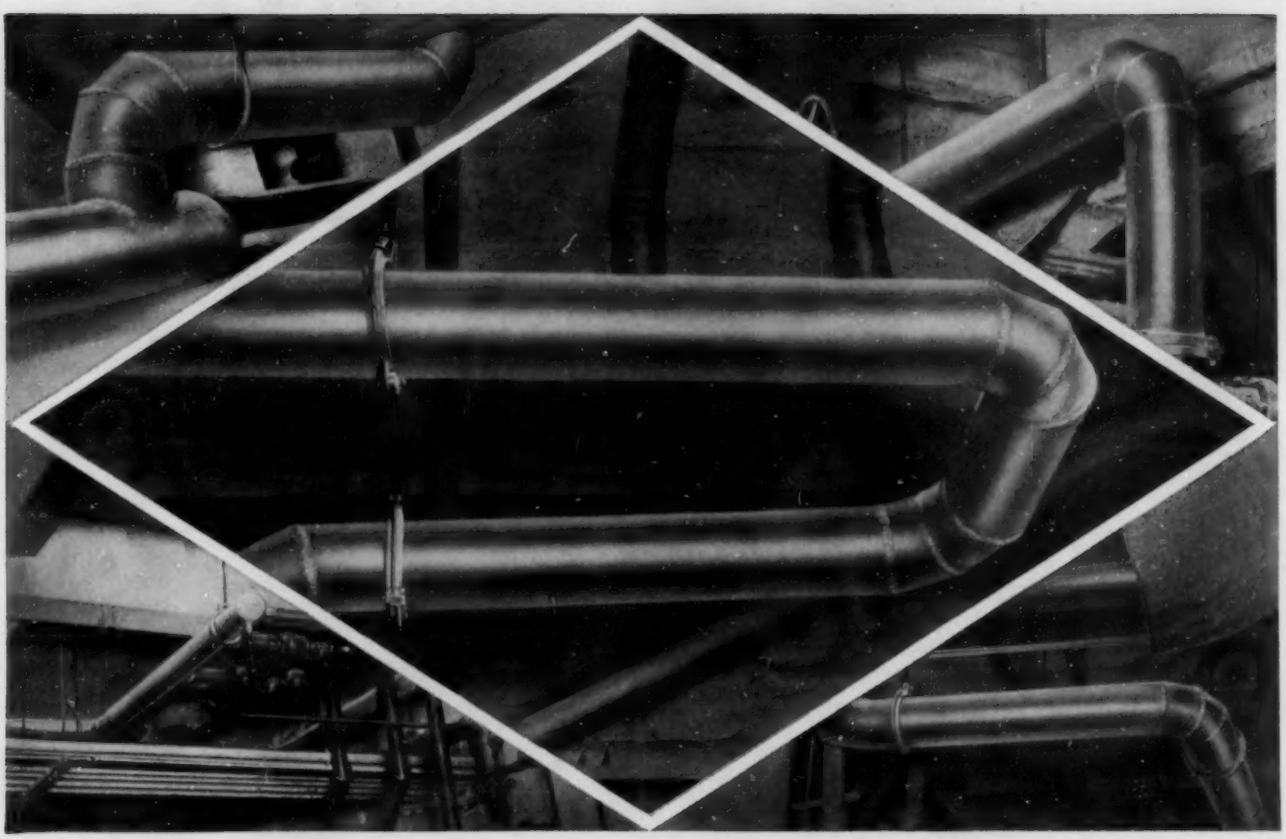


PUBLISHED MONTHLY FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING



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THE AMERICAN WELDING SOCIETY JOURNAL

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EDITORIAL AND GENERAL OFFICES
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A Shot-Welded Stainless Steel Truck Body

A Light-Weight Car for City Traction Service*

By M. B. BUTLER, JR.†

THE latest step in the direction of city transportation is the new light-weight five-section car for the New York Rapid Transit Corporation. With a car weight of 250 lb. per passenger and with each axle motor driven as well as braked to the full extent of available traction, local service can be speeded up to almost express schedule.

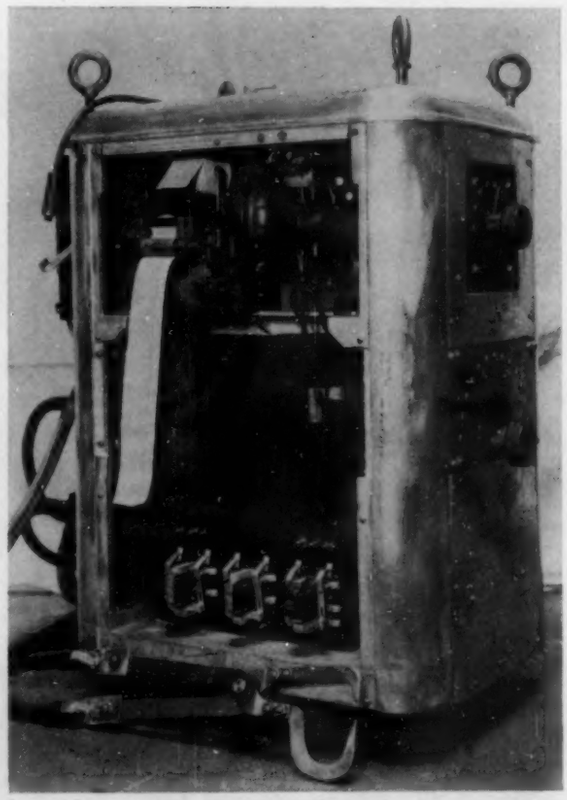
Comfort of Passengers

Paralleling advances in structure and power are considerations of public comfort. All trucks are mounted in noise- and shock-deadening rubber. The floor is of inlaid cork, which in itself not only insulates against sound and cold, but is easy on the feet.

Through articulation, adjacent car ends of two sections rest on a common truck, thus, in this case, eliminating four trucks. The principle is not new and has already been proved in service. Further advantage lies in the fact that the various sections perform as a single unit instead of so many individual cars whose ends fight each other in starting, stopping or negotiating curves. The five sections can, therefore, be properly termed an articulated car rather than a train.

Importance of Light Weight

The true cost of excess weight has so far only been sensed; it has never been fully reduced to dollars and cents. Whatever costs are available already indicate



The Control Mechanism Is Mounted in a Box and a Record Made of Each Spot

* Presented at Fall Meeting, A. W. S., New York, October 1–5, 1934. Some of these cuts loaned through courtesy of *Iron Age*.

† Welding Engineer, Hi-Tensile Division, Edward G. Budd Manufacturing Company.

potential economies in excess of those ever achieved by labor saving. Weight saving has suddenly become recognized as a fruitful field of endeavor.

Weight saving by mere weight reduction is not to be confused with true light-weight construction. The first accomplished the end at a sacrifice of strength and security; the latter, by proper proportioning of loads to materials, can actually increase the factor of safety after a very substantial lessening of weight. This involves an effective use of superior materials.

Few materials, however, fit into all phases of this picture. Efficient sections usually involve closed members like a tube, and these are difficult to protect against corrosion. Many metals which are sufficient in this respect lack strength or capacity for proper assembly. So far, only one material seems to combine in itself all requisites. It is 18–8 stainless steel.

Properties of Stainless Steel

This metal not only resists atmospheric corrosion but attacks by most chemical agents as well. It requires no paint.

It can be given, by cold rolling and without heat treatment, a tensile strength superior to that of spring steel, and yet retains the toughness of softer material.

Fabrication

As used by the Budd Company in car body construction, 18–8 is rolled into bright, shiny strips. The tensile strength specified is not less than 150,000 lb. per sq. in. These strips come in large coils and are then drawn through a series of rolls to form the required sections. Few exceed 0.050 in. in wall thickness, and some material is as thin as 0.010 in. The sections favor squared corners instead of rounds, for it is always easier to assemble squares. Flanged channels predominate, and these are later converted to closed sections by welding cover strips over the open face.

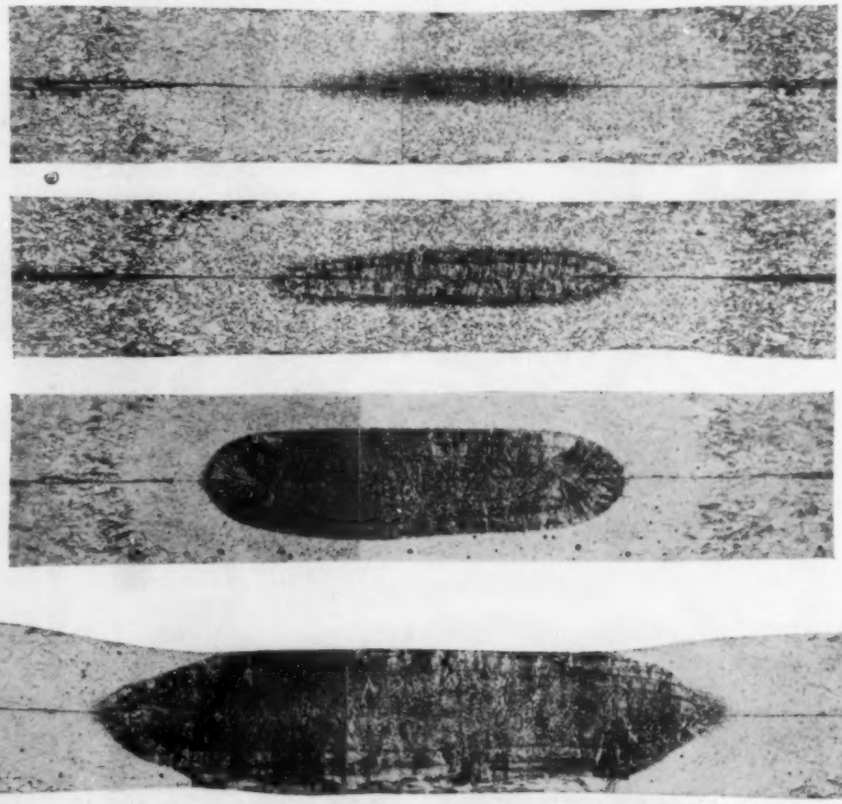
The sections and methods of fabrication have been developed with a view to assembly by welding. The car structure follows a simple procedure whereby vertical or diagonal members dovetail between horizontal mouldings so that all eccentricity of loading is avoided. Attachment is usually by gusset plates and is sufficient to develop the full strength of the members.

Final assembly follows upon a series of progressive sub-assemblies, starting with posts, floor beams and roof carlines. The first are then organized into shear panels and later built into the side frame assembly. Roof carlines form the skeleton for a roof assembly, while the floor beams drop into place at the time of attaching roof to side frames. The end trusses complete the box. Stringers are then laid over the floor beams and four of these, two above and two below the beam, are trussed into a central compression buffing member. Above the stringers are laid corrugated flooring strips, welded to each other to form a continuous floor plate which ties into the sides and stringers.

Determination of gage and structural sections results from an elaborate stress analysis. In this, aircraft methods are largely used. Graphical determination of stresses is followed by a so-called Williot diagram which, in brief, parallels the stress diagram except that resulting deflections rather than loads are used. Rarely, however, is any structure, which is complicated by doors and windows, graphically determinate throughout. Redundancy is inevitable. Its solution may be intricate, but the structure need not be.

As soon as a complete stress diagram is available, the

Welds in Stainless Steels of 0.012 in. Thickness Strips

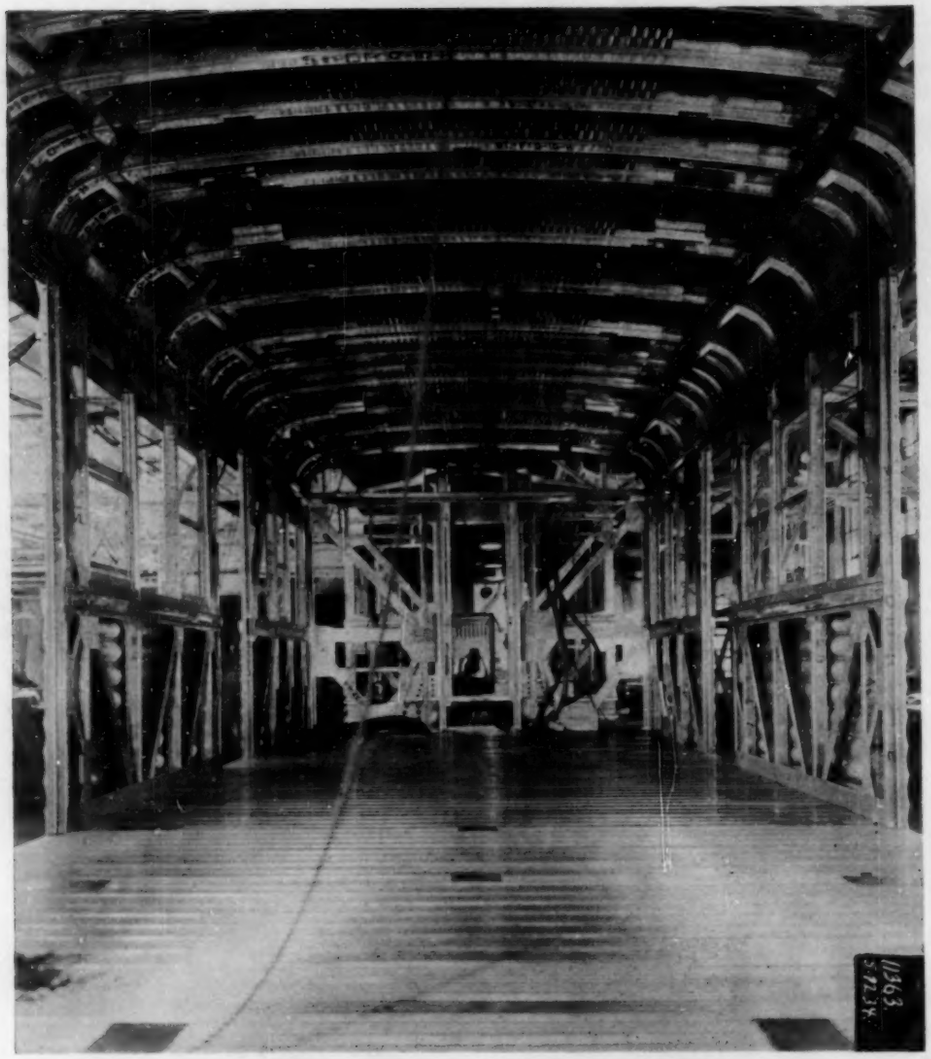


Insufficient Fusion, Giving a Semi-Fused Weld

Insufficient Fusion or Cold Weld

Shot Weld with Correct Fusion

Overheated Weld, a Case of Too Much Fusion



Interior View, Showing the Stainless Steel Construction of the Roof, Sidewall and Floor

choice of sections becomes a simple matter of proportioning cross-sectional area to load. No sections exceed 25,000 lb. per sq. in. which gives a factor of safety of six.

It is, perhaps, timely to note here that in the Budd type of construction, the side and deadlight panels do no structural work. All shear forces are taken by a distinct truss system. This departure from conventional practice results from an elaborate study of alternate methods. An incidental advantage lies in the fact that the outer sheathing will not show the highlights and shear lines which are seemingly inevitable in flat plate side walls. In this particular car, with its short length between supports and high loading per square foot of floor area, shear forces become a more serious factor than does bending, and the side framing assumes a correspondingly greater significance.

Here the question naturally arises as to the ultimate importance of the effort and cost of light-weight construction. Thanks to it, the body structure of all five sections without trim or appointments has been reduced to some 40,000 lb., which, when compared to the car weight of 159,000 lb., is 25% of the whole. The percentage, however, remains about normal since the urge toward elimination of needless weight has been extended into every department. A comparable train built according to convention would weigh at least 325,000 lb. Figuring then on a low estimate of $.02 per lb. per year, the difference in annual operating cost amounts to $3200. Figuring on comparable acceleration, the increased motive power involves an initial outlay of some $30,000 more, with an interest on this investment of $1500 per year. The sum of these two items alone represents a 5% interest on $94,000. Other economic advantages need not be advanced, nor is it necessary to justify the lighter equipment by emphasizing the fact that heavier cars accelerating and braking at the newer rates would probably involve reinforcing and higher maintenance of the elevated structure itself.

The "Shotweld" System

All the world has heard of the "Shotweld" system and its application in the fabrication of stainless steel for light-weight railroad cars, truck bodies, aircraft structures and shipbuilding. To the layman it implies, perhaps, a mysterious new method of welding. Actually, it is a carefully controlled spot-welding operation, through its careful control of the elements that enter into the making of a successful spot weld in special alloy steels, such as the "stainless group."

By this process of welding, structures are made up of sheets or strips of stainless steel spot-welded together, in which the desirable properties of the steel, such as its strength and its resistance to corrosion and fatigue, have not been materially impaired in the fabricated structure by the spot-welding operations.

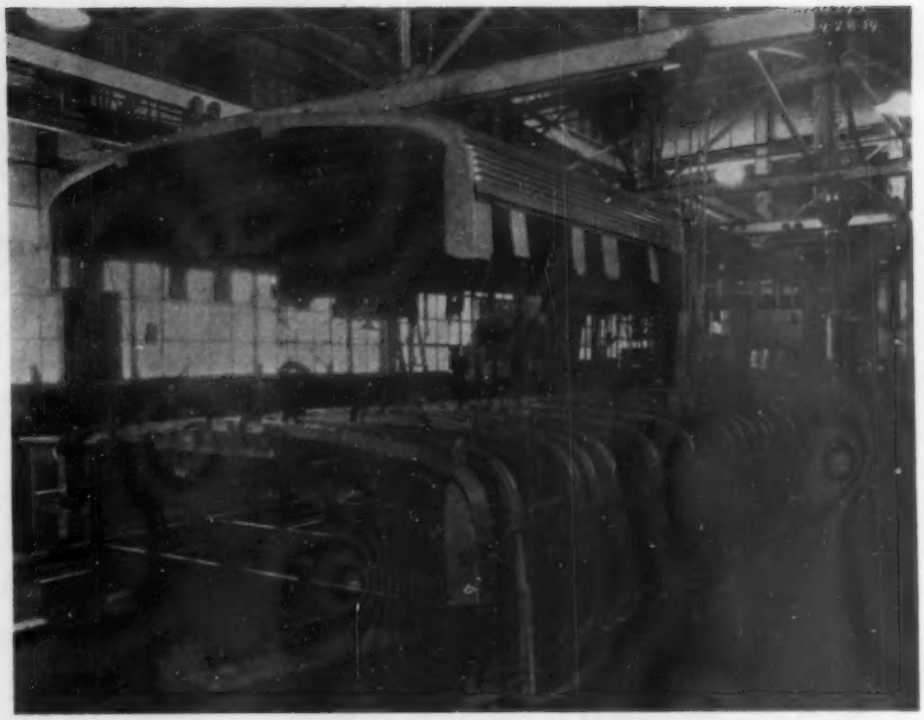
Although there are a variety of the so-called stainless steels, this particular paper has reference to those stainless steels which are nickel-chromium-alloy steels known as austenitic stainless steels and preferably containing approximately 18% chromium and approximately 8% nickel and below 0.16% carbon.

Ordinarily, the welding of this cold-worked steel is unsatisfactory. First, because the steel is annealed by air cooling when brought to a temperature below its melting point and, if too much of the area of the steel is allowed to become annealed, it weakens the structure of the joined areas due to the fact that the strength of the annealed steel is considerably below that of the cold-worked steel; and second, because there is a temperature range of the metal at which carbide precipitation may occur, and this carbide precipitation will result in destroying the resistance of the metal to corrosion as well as its homogeneity. This latter feature is true as to both the cold-worked and the annealed stock.

Taking for example the 18–8 stainless steels above

mentioned and cold-rolled to a tensile strength in the region of about 150,000 to 200,000 lb. per sq. in., if it is heated to a temperature within a certain critical range (about 900 to 1500° F.) and the heat held within that range for too long a time, the carbon which is normally in solution will be precipitated out as carbides and dispersed along the grain boundaries and/or slip planes. For the annealed stock which is usually employed with an ultimate tensile strength of about 90,000 lb. per sq. in., the critical range for carbide precipitation is about 1100 to 1400° F. In this state the metal is no longer homogeneous and very materially loses its resistance to corrosion and fatigue, and also its ductility and resistance to impact.

The energy consumed or heat generated in a spot weld is I^2Rt, where I represents the current, R the resistance and t the time.

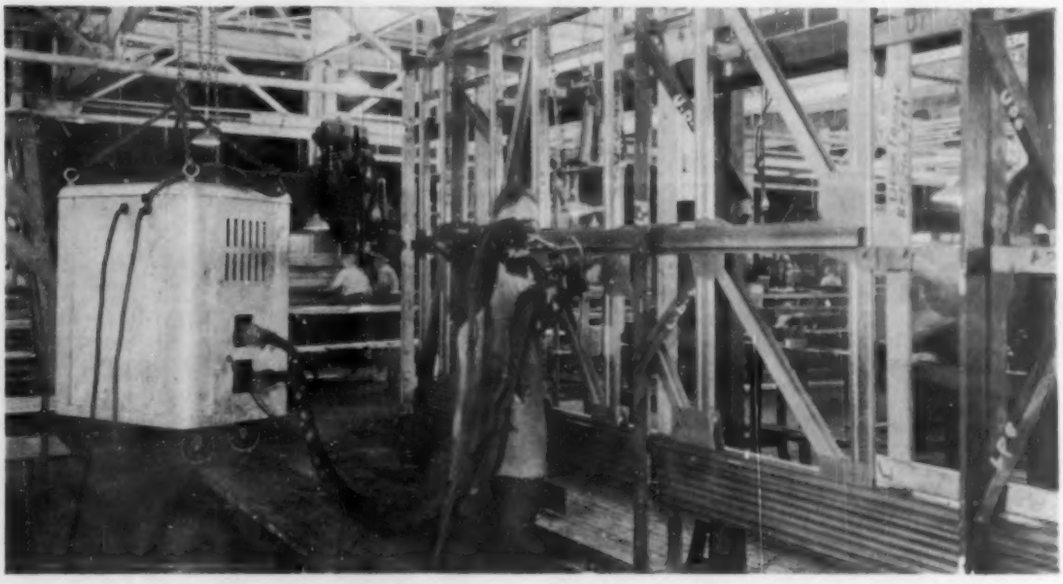


Above, a Car Roof Welded into a Single Unit. Below, Members Assembled for the Welding of Roof for Another Car

Inasmuch as the electrical resistivity of the austenitic stainless steel is several times that of the carbon steel, the heat generated with a given current will be much more rapid in the body of the metal than in the case of ordinary carbon steels.

The "Shotweld" system of construction in its spot welding takes advantage of the relatively low melting point of stainless steels and their great fluidity immediately upon fusion; and by utilizing very large welding currents sufficient heat to fuse the metal and produce an excellent joint or weld is generated in a small fraction of a second of current application; and by thus limiting the time of application of the relatively large current and also limiting the amount of current to not substantially more than necessary to affect the weld in this brief period of time, the period of the dwell of the heat in the metal is made less than that which would substantially impair the desirable characteristics of the overlapped welded portions, such as the strength and anti-corrosion characteristics of the metal.

Stating the matter in another way, the welding operation should be carried out in such a manner as to insure a steep heat gradient in the metal both on the rise of temperature, due to the application of the current, and on the fall of temperature in the quenching of the metal after the current is cut off. In this way the heat which has a deleterious effect upon the steel is limited both in degree and time of application or amount to not sub-



Stainless Steel Members Are Fabricated by the Budd Shotweld Process. Side Frame Unit Being Assembled

stantially more than that necessary to affect the weld, and, therefore, it will have a minimum effect in impairing the desirable characteristics of the metal. A rapid rate of introduction of the heat, i.e., the steep heat gradient on the rise will be effected by utilizing the relatively large currents for the brief period of time and the rapid fall of temperature, i.e., the steep down gradient will be effected both by the rapid introduction of the heat and by utilizing not substantially more heat or energy than necessary to properly weld the metal, thus enabling the metal to be more quickly quenched by the conduction of the surrounding cool metal and the electrodes. The electrodes may be water cooled if desired. If the heat is relatively slowly introduced the metal surrounding the weld would not remain cool and would, therefore, be less effective in quenching the metal of the welded zone. Also, other factors being the same, the more heat or energy put into the weld the more time required to quench the metal.

These deleterious effects, resulting from the introduction of an excess of heat or undue dwell of heat, may take place without being detected from the mere appearance of the welded zone and may only be discovered by microscopic examination or by other tests for strength and corrosion; so it is important to properly and accurately regulate both the amount of current and the time of application thereof to insure uniform and reliable welds.

Pressures used should be relatively high in order to assure good point contact and to insure the desired rapid heat conduction from the interior of the weld out through the electrodes.

By this method of welding, the resulting diameters and areas affected by the heat of welding are much smaller than compared with ordinary spot welding. The weld itself does not extend quite to the outer surfaces of the two adjacent sheets of metal, its thickness being preferably from 50 to 80% of the total thickness of the two sheets being welded.

The currents used are substantially higher than those in ordinary steel and the application much shorter.

Actual values will depend upon the current density, time of application, size of electrodes, whether the electrodes were water cooled, pressure and thickness of the spot being welded.

Accurate devices for regulating the amount and time of application of the current have been developed, so that they can be properly controlled.

The timing apparatus is capable of actually measuring and cutting off the current within desired very short periods.

The following examples will illustrate some instances of the use of the "Shotweld" system as applied to spot welding of parts made of cold-rolled austenitic stainless steel having an ultimate strength of about 160,000 lb. per sq. in. It is to be understood that the figures herein given in these examples for the different individual factors or elements involved, are given by way of example only, and that one or more of them may be varied with respect to the others to get a different but satisfactory combination of factors so long as the total heat delivered is sufficient to make a full weld and the dwell of heat in the welding zone is insufficient to produce the above pointed out deleterious effects on the joint, i.e., is insufficient to substantially deleteriously affect the area of the overlapped welded portions of the metal as a whole, both as to its resistance to corrosion and its tensile strength.

In the examples the current values are given in terms of the density per square inch of area of the welds themselves (measured transversely of the direction of current flow), since this has been found the most accurate method of comparison. The sizes of the welds for given electrode diameters may be varied by varying the current density and time. The electrode sizes are varied largely to accord with the dimensions of the work being done, e.g., thickness of gage, stiffness and relative alignment of parts, pressure needed to draw them together, accessibility to the spot to be welded, etc. In the welding of stock from 0.008 to $^1/_{16}$ in. the diameters of electrodes have varied from about $^3/_{16}$ to about $^1/_2$ in.

Example A	
Gage, 2 thicknesses, each	0.010 in.
Diameter of electrode	$^3/_{16}$ in.
Area of resulting weld	0.00165 sq. in.
Total electrode pressure	75 lb.
Welding time	0.0083 sec.
Welding current	1472 amp.
Current density in welded area	894,000 amp. per sq. in.

Example B	
Gage, 2 thicknesses, each	0.050 in.
Diameter of electrode	$^3/_8$ in.
Area of resulting weld	0.0143 sq. in.
Total electrode pressure	500 lb.
Welding time	0.0833 sec.
Welding current	4270 amp.
Current density in welded area	298,200 amp. per sq. in.

The light-weight system of construction and the Budd "Shotweld" system of stainless steel fabrication are already the subject of a number of issued patents covering structures, processes and apparatus.

Novel Weld Saves $475

By H. S. ORWIG†

A BROKEN crankshaft, belonging to a 45-h.p. Diesel 3-cylinder engine weighed about 350 lb. The price of a new shaft and bearings was $550. The old shaft was welded and machined at a total cost of $75 or a saving of $475.

In preparing the job, the shaft was blocked on a lathe to line up as nearly true as possible. The broken section was veed out with a cutting torch from one side to the center. A bead was then run through with the arc welder and the sides tackwelded sufficiently to allow the shaft to be turned over and the operation repeated on the other side. Now being strong enough to take out of the lathe, the shaft was built up a little at a time until the welded portion was larger than original size.

The shaft was then put back into the lathe with a press mounted over it and straightened to within 0.030 in. of true as recorded by the dial gage. Following this, all main bearings were ground 0.050 in. undersize. With bearings rebabbitted and bored to fit the shaft, everything lined up and turned freely after being assembled. The engine, since run well over 100 hrs., is performing excellently.

† Publicity. Harnischfeger Corp.

A Welded Steel Press

By CHAS. H. JENNINGS†

THE modern trend in heavy machinery design is exemplified in the large mechanical press recently fabricated for the Bliss-Marquette Company of Toledo, Ohio. This press was of welded construction and both rolled steel plates and castings were used in order to accomplish the most efficient design.[1] The extremely large size of the press parts and the large heavy plates used in their construction makes this job of particular interest from the welding standpoint.

The weight of the completed press is 750,000 lb. and the over-all height and length are 348¾ and 338 in., respectively. The working capacity is 1800 tons plus the cushion load of 300 tons. The bed of the press which is 252 in. between housings and 68 in. wide was designed on the basis of a 2500 ton working load in order to avoid excessive deflection. A view of the assembled press is shown in Fig. 1. In connection with this figure it will be noted that the largest part, the bed, is located below the floor and that this part, which is 120 in. high, constitutes more than ⅛ of the total height of the press.

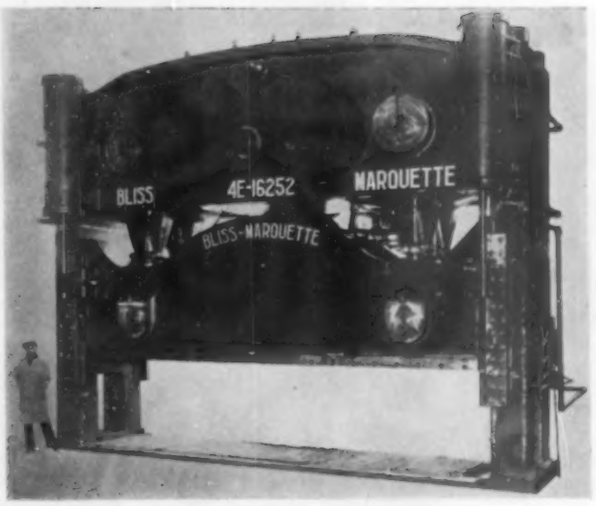


Fig. 1—The Press

In designing the welding on this press it was attempted to design the parts so that the heavily stressed welds were subjected to compression loads. This point is illustrated in the photograph of the welded bed (Fig. 2) where it will be noted that the cross numbers at the ends, which carry the four 9 in. diameter alloy steel through bolts, extend to the outer edge of the side plates. This construction afforded a bearing surface between the parts and placed the welds in compression.

All important strength welds were made with our heavily fluxed electrodes. These electrodes are intended for down-hand welding, consequently it was desirable that the parts be properly positioned during welding. The positioning of heavy structures is a difficult and expensive operation, consequently sub-assemblies were made whenever possible. Also, in many cases butt welds were used in place of fillet welds because this design eliminated the extra positioning that always accompanies fillet welds. In cases where the welds were lightly stressed, or for appearance only, lightly coated arc-welding electrodes were used.

In connection with the large use of butt welds on this structure the question of residual stress was, of course, considered. The use of the proper welding procedure, however, eliminated all troubles from residual stresses during the fabrication process and the strain annealing of all the finished parts insured that any residual stresses that might have been produced during welding were eliminated.

The press bed, which is the largest single part of the structure, is 338 in. long, 120 in. high and 120 in. wide and had a rough weight of 157,000 lb. A photograph of the completely welded bed is shown in Fig. 2.

The bed consisted essentially of two 5 in. thick side plates joined by four spacer plates and two box section ends. The spacer plates were joined to the side plates by fillet welds and the box section ends were joined to the side plates by butt welds. The fillet welds were used on the spacer plates because it was desired to use intermittent welding and this would have been impracticable with butt welds.

A 9 x 12 in. formed rib was butt welded to the bottom

Fig. 2—Completely Welded Press Bed

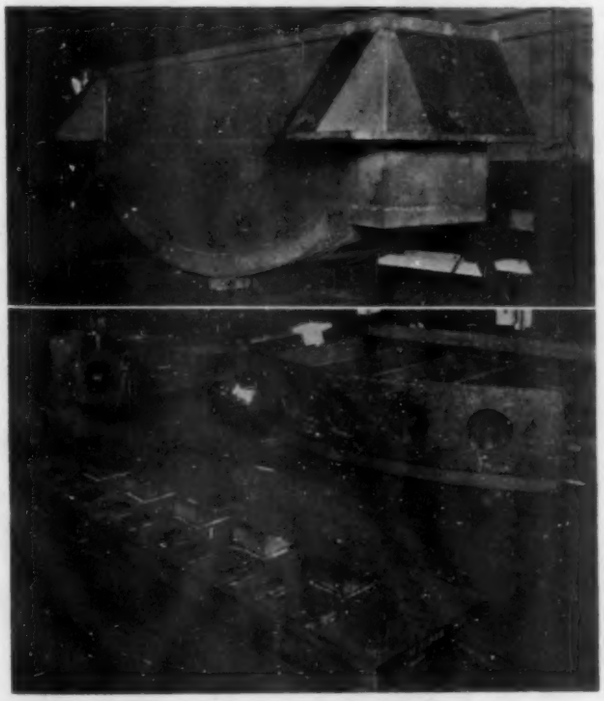


Fig. 3—Partially Assembled Press Bed

† Westinghouse Electric & Manufacturing Company.

[1] Chas. H. Jennings, "Physical Properties of Welded Cast Steel," JOURNAL OF THE AMERICAN WELDING SOCIETY, Oct. 1933.

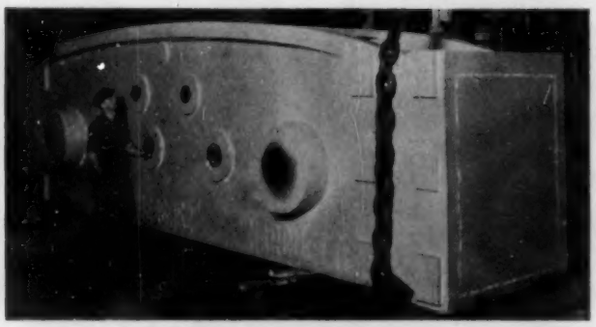


Fig. 4—All-Welded Crown for Bliss-Marquette Press

of each side plate and a 5 x 12½-in. plate butt welded to the top (see Fig. 3). The use of butt welds for these joints made it possible to lay the side plates flat on the floor in order to assemble and weld them. While these joints were being welded it was also possible to weld some of the minor details in place as shown in Fig. 3.

In order to eliminate distortion of the parts, when welding the large side sections the welds on one side were half finished, the pieces turned and the opposite welds completed, and then the one-half finished welds on the first side completed. No trouble was experienced from distortion by using this procedure.

The crown of the press is shown in Fig. 4. The outstanding feature of the crown is the seven cast-steel bosses that are welded into each side. These bosses were turned to a light shrink fit and shrunk into previously bored holes in the side of the crown. Butt welds were used to weld the bosses into the plate. The use of butt welds in this case made it possible to lay the side plates flat and do all the welding in this position. The light shrink fit was used on the bosses to prevent high welding stresses.

Pads and letters were also welded in place while the bosses were being welded into the side plates.

The slide, uprights, flywheel bracket and motor bracket (see Fig. 1) were all welded in a manner similar to the bed and crown. The advantages of butt welds and sub-assemblies were used in order to minimize the cost and difficulty of fabrication.

Acknowledgments

The writer wishes to acknowledge the assistance rendered by Mr. F. J. Rode, Chief Engineer and General Manager of the E. W. Bliss Company, and Mr. D. B. Charters, Manufacturing Engineer of the Westinghouse Electric and Manufacturing Company, for supplying information regarding this press.

Qualifying Operators of Welding Equipment under A. S. M. E. Boiler and Pressure Vessel Codes*

By ALEXANDER KIDD†

THE A. S. M. E. Unfired Pressure Vessel Code states in Paragraphs U-69 and U-70 that "Each manufacturer shall be responsible for the quality of the welding done by his organization and shall conduct tests of the welders to determine their ability to produce welds which will meet the required tests," and goes on further to state that "the testing of a welder shall be effective for a period of six months only, at the end of which time a repetition of the tests shall be made by the manufacturer, except when the welder is regularly employed on production work embracing the same process and type of welding, in which case the test may be effective for a period of one year." However, there is a further clause reading as follows: "An authorized inspector shall have the right at any time to call for and witness the making of test specimens of any welder, and to observe the physical tests."

Let us consider the actual merits of these demands. Is it worthy of the expense involved, should the purchaser be called upon to pay for this expenditure, and what assurance has the purchaser that the benefits derived from such qualification tests are sufficient compensation for the expenditure?

Before we discuss the merits of these rules, let us consider first what precautions the reliable manufacturer takes before employing operatives to represent his organization. These prospective operatives are required to prove their ability to weld by making suitable test plates. It is here appropriate to consider the motive of a reliable manufacturer in testing his operatives. If for no other reason, they would be tested so that subsequent expense by reason of inferior work would be eliminated.

These tests are generally made under the same circumstances and the same procedure as employed in the construction of welded products. Suitable tests are run to prove that the applicant is capable of producing welds which will meet the requirements and specifications that the manufacturer will be called upon to meet, namely: 2 full section tension specimens; 2 reduced section tension specimens; 2 nick-break specimens; 2 bend test specimens. It is to be noted at this point that necessary material at current prices must be purchased, as well as labor expended in both preparing the edges for welding and machining of test coupons for the physical tests. This is a very expensive item, in view of the fact that out of every hundred operatives that present themselves for the position, it is safe to say that a maximum of 25 are suitable for quality welding, and there are some cases known where this proportion has been much less.

I would call your attention to the fact that in a recent installation of a large industrial power unit in the east, there were approximately 400 men who presented themselves for positions as operatives of welding equipment, and were requested to make qualifying tests. Of this number, approximately 20 men were accepted, the balance failing in their tests. It has been intimated

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† Assistant Works Manager, The M. W. Kellogg Company.

to the writer that the cost of qualifying each accepted operator represented $600.00.

In spite of all precautions and expenditures made by the manufacturer, he still has no definite assurance that the man who has been accepted can, and will, produce satisfactory welds. This is true due to the fact that his test plates were made under the most favorable working conditions and with the definite understanding and feeling that the plate that was being made was intended to give the most favorable results.

The writer must confess that there seems to be no means by which you can get away from the necessity of qualifying operatives, because something of this kind must be done in order to prove whatever ability resides in the person being tested.

Let us now return to our original questions, the first being is it worth while to have the six-month or yearly qualification requirements. It is quite obvious at this stage of our discussion that we must distinguish between the manufacturer producing Class One welded products as the major portion of his business and Class Two and Three as the minor portion, and the manufacturer producing Class Two or Three as the major portion of his business. I would like to state that it is my opinion that where the operatives employed are producing continuously Class One products, I do not consider it a justifiable expenditure to qualify the operatives periodically. It is the writer's opinion that test plates as called for, either in the Power Boiler Code of two test plates per vessel, or in the Unfired Pressure Vessel Code of two test plates for every 200 ft. of weld, that it is unnecessary and an absolute economic loss to do any further qualifying of operatives. Any effort to force this requirement would be most certainly imposing a grave injustice on the purchaser, in that he must ultimately bear the expense with no additional assurance of protection, and a hardship on the manufacturer in breaking up a production schedule to qualify an operative. The ridiculous aspect will at once appear to any one when he considers that under the rulings in the qualifying of operatives, a condition can occur, and has occurred many times, when an operative is compelled to stop the production of satisfactory welds which are passing all requirements, to make a test plate.

At the same time, the writer believes that an inspector representing the purchaser should not be given the power to demand at will that operatives employed on his particular job be qualified to suit his individual desires, and that he should accept a statement, either notarized or otherwise, from the manufacturer that the particular operatives on his job have previously successfully prepared test plates, and have been working on power boilers or on Class One vessels.

The writer recognizes only too well the great difficulty in drawing up rules and regulations, whereby the human element will be controlled in all the ramifications, that is to say, he understands thoroughly how difficult it is to set up rules that will, for example, insure through the qualification of an operative, first-class production on the part of the operative so qualified, and it is the writer's firm opinion that this cannot be successfully accomplished one hundred per cent.

It is the writer's suggestion, therefore, that other factors be considered in supplying this deficiency. For example, why isn't it most reasonable to expect that a manufacturer who is continuously, for the greater part of his business, supplying Class One unfired pressure vessels or power boilers to be so set up, constituted and disposed toward quality work, that work done by him would be presupposed to embody all of the high qualities that are to be expected under the general definitions and requirements of code work. In other words, it is insufficient to assume that simply because an operative has qualified through a test plate, that he will invariably do good work in production. The test plate becomes the yardstick by which the purchaser judges the quality of the operative, but production is the yardstick by which the manufacturer ultimately judges the operative. It goes without saying that no manufacturer can be successful who does not continuously do good work, therefore, a certain amount, if not a great deal, of value should be placed upon the type of work that the manufacturer is continuously turning out. For example, in the case of a manufacturer whose principal production is Class One vessels, it is fair to assume that the operatives operating in his shop are capable of turning out as good work, if not better, than is called for in any code covering Class Two or Three, and for this reason it seems a useless waste of money, time and energy, to consider that the qualification test is the sole yardstick by which to judge the value of the completed article, or the ability of that particular manufacturer to produce invariably the article in accordance with the letter and spirit of the code requirements.

It must be manifest to anyone that there must be a continual check on the quality of welding, and of the technique of any manufacturer, if he is continually meeting the regular tests as called for in the Power Boiler Code as well as Class One specifications of the Unfired Pressure Vessel Code, which are as follows: 0.505 Bar Test; Reduced Tensile; Free Bend; Density.

A further test which would be satisfactory, in the writer's opinion, would be where reinforced nozzles are permitted in the welds, that a portion of the weld metal removed for this nozzle opening be tested in accordance with the Code requirements. This, of course, would only be a spot check at random on a few of the operatives, but would be a fair indication of the type of welding being produced.

Summary

It is the writer's mature opinion that there should be different requirements for the qualifying of operatives in shops where the technique and procedure vary, particularly with respect to X-raying equipment. This difference should be where the manufacturer is X-raying and preparing test pieces in accordance with Class One Unfired Pressure Vessel or Power Boiler Codes, that this apparatus and test pieces be sufficient to qualify that shop. Where no X-raying equipment is available, and consequently no Class One work is done, qualification tests should absolutely be made periodically, since there can possibly be no other test presented to qualify either the shop or the operatives.

Hard-Facing*

By E. H. LE VAN†

ABRASIVE wear is a problem of major importance in practically every industry. Wherever equipment wears rapidly, repair or replacement costs are apt to be large, and lost time for shutdowns is excessive. To obviate the necessity for continuous replacements and shutdowns, practically every industry has adopted the process of hard-facing for protecting machine parts that are subject to excessive wear.

Hard-facing is the process of welding onto wearing parts a coating, edge or point of a metal highly capable of resisting abrasion. This means that a protecting layer of wear-resistant alloy covers the surface that is normally worn away rapidly and protects it from wear. The process is applied equally well to new parts before their first use, or to old worn parts.

Hard-facing has many advantages and has proved to be an easy and economical method for keeping equipment on the job without losing time for repair or replacement of worn parts. The cost-reducing features of hard-facing may briefly be summed up as follows:

1. Longer life of equipment.
2. Fewer replacements, with resultant savings in labor charges and lost production time.
3. Utilization of cheaper base metal.
4. Salvaging or reclaiming of worn parts.
5. Savings in power consumption.
6. General increase in operating efficiency.

It is hardly necessary to state that friction is never present without the accompanying generation of heat. When one surface moves in contact with another nearly all the work done is converted by friction into heat which is liberated on the contacting surfaces producing high local surface temperatures. This may be illustrated by the method used by the Indians for lighting fires by rubbing sticks together. Tests show that, under severe abrasive conditions, surface temperatures often momentarily approach a red heat even though there may be little evidence of such high temperatures to the eye because of rapid dissipation of the heat into the body of the metal and the air. A laboratory experiment using a pyrometer shows that, if the ends of an open thermocouple are held by hand against a rotating steel disk, a temperature of 1500° F. will be generated on the surfaces in contact although to the eye there is but little evidence of heat.

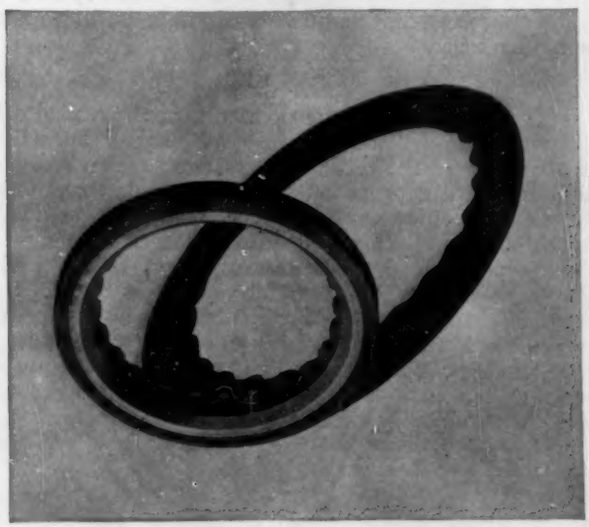


Fig. 1—A Typical Automotive Valve Seat Insert Hard-Faced with Haynes Stellite

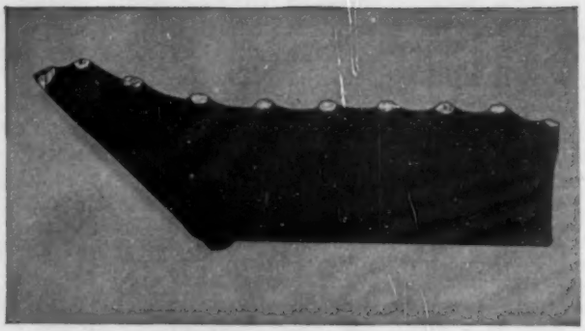


Fig. 2—This Plowshare, Hard-Faced Only in Spots, Plowed 15 Acres of Sandy Missouri Soil. Note How the Balance of the Share Has Worn Away

It is probably true that as a rule harder alloys will wear less rapidly than softer ones, but the effective hardness is the actual hardness under working conditions. Hence, hardness as a criterion of wear resistance must be measured at working temperatures, which are usually high. This indicates that "red hardness," or the ability to remain hard at high temperatures, and not cold hardness, is the true measure of ability to resist wear.

All alloys soften when heated to the red range, but the rate of softening varies greatly. High-speed steel softens less when heated than does plain-carbon steel, and the cobalt-chromium-tungsten hard-facing alloys soften to a lesser degree than any alloys containing appreciable amounts of iron. These non-ferrous alloys consist of metals that have been specially developed to combine maximum wear resistance with excellent welding properties and derive their extreme resistance to wear and abrasion from their property of "red hardness." At temperatures above 1100° F., these alloys are harder than any other known materials, except those of the tungsten carbide class. It is this important property of red hardness which undoubtedly accounts for the superior results obtained by the use of these hard-facing materials.

* Presented before Fourteenth Fall Meeting, American Welding Society, New York, October 3, 1934.

† Haynes Stellite Company, Kokomo, Ind.

Fig. 3—Hard-Faced Hot Clinker Grinding Ring Which Lasted 10 Times Longer Than an Unfaced Ring

For conditions of severe abrasion and especially where abrasion is accompanied by heat, their use has become standard.

Besides the non-ferrous alloys, there are two other types of hard-facing materials which merit discussion. The first is tungsten carbide, the so-called diamond substitute, which cannot be applied like welding rods by melting with the oxyacetylene flame and is, therefore, used in cast pieces of various sizes which are held in place by a binding material. Tungsten carbide is also available as Composite Rod which consists of screened sizes of sharp, irregular shaped grains held in a welding rod binder. The diamond substitutes find their principal use for hard-facing oil well drilling tools and for other parts subjected to especially severe abrasion.

The other group of hard-facing materials comprises alloys having an iron base and containing such elements as chromium, manganese, tungsten, silicon, etc. These materials are used for reconditioning gyratory crusher mantles and similar parts which must withstand shock and impacts as well as abrasion. They are also used as base materials under the more wear-resistant non-ferrous alloys and as a binder for the diamond substitutes.

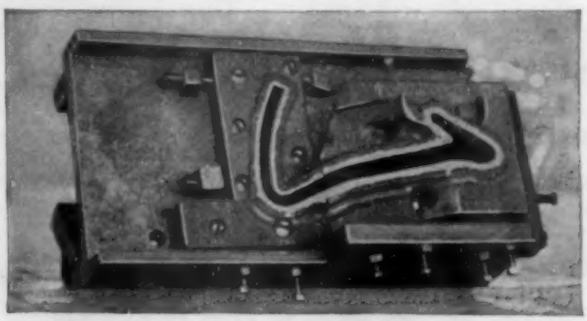


Fig. 4—This Hard-Faced Hot Trimming Die Gave 14 Times More Pieces Than a Steel Die

Because of the enormous scope of hard-facing in practically every industry, it is impossible here to do little more than merely mention the fields of application and show a few typical examples of hard-facing procedures and note the economies resulting from them. However, a short survey of the more important fields of application, together with typical uses in these fields, will give a picture of the extent of hard-facing in these industries.

The automotive industry, which has been a pioneer in adopting alloy steels and modern improvements, has adopted hard-facing for not only its manufacturing machinery, but also for wearing parts of automobile motors. An example of the use of hard-facing material in automobiles is the exhaust valve seat.

Several prominent manufacturers of heavy-duty trucks and buses have standardized on exhaust valve seats that are hard-faced with the non-ferrous alloy Haynes Stellite because these hard-faced seats last longer, require less attention and reduce valve grinding and adjustment to a minimum. As is shown here, these seats generally consist of a removable steel insert with the hard-facing material applied to the beveled seating surface. Ordinary cast-iron valve seats of heavy-duty trucks and buses must be ground practically every 10,000 miles. Tests have proved that the hard-faced valve inserts will operate for 10 to 20 times this mileage without regrinding. This means lower gasoline consumption, lower compression losses and increased power, mileage and all-around motor efficiency. The performance of these special valve seats in truck and bus motors under the severe conditions to which they are subjected indicates that such seats will outlast the life of passenger car motors. (Fig. 1.)

Fig. 5—Hard-Faced Bottom Die for Stamping and Forming Grease Tins. These Dies Last 4 Times Longer

The agricultural industry was one of the first to adopt hard-facing. The problem of counteracting abrasion on cultivating machinery has, in a large way, been solved by the use of wear-resistant materials on parts that come in contact with the soil.

A typical example of the use of hard-facing material on agricultural implements is shown in its use on these plow shares. This share was hard-faced in spots only to demonstrate the difference in wear between the plow-share steel and the hard-facing material. Note how the steel has worn away between each spot of hard-facing. (Fig. 2.)

This shows a share that has been completely hard-faced with a layer of wear-resistant material on the point and all along the entire cutting edge. The layer of wear-resistant material on this share is $^1/_{16}$ in. thick and actual tests have shown a life ratio of as much as 5 to 1 over an ordinary unprotected share. Not only will this share require less sharpening but it will maintain a keener cutting edge and, therefore, effect considerable saving in power and do a much more efficient job of plowing.

The cement industry likewise is a large user of hard-facing material. Equipment used to manufacture cement is necessarily subjected to extreme abrasion. The fine particles of cement wear away the best steel in a very short period and prior to the advent of hard-facing materials the maintenance of such parts as grinder rings was a real problem.

Figure 3 is a hot clinker grinding ring that has been hard-faced with a cobalt-chromium-tungsten alloy. Tests run by an Illinois cement company showed that these hard-faced rings lasted 4640 hrs. whereas other rings were unfit for service after 470 hrs. As a result of these tests the use of the non-ferrous alloy has become standard in this plant. Other examples of hard-facing in cement plants are: conveyor screws, gudgeons, conveyor sleeves, pulverizer hammers, roll crusher teeth and crusher mantles.

Perhaps no other industry meets such severe conditions of abrasion as the excavating industry. The wear on equipment designed to handle sand and gravel is terrific and it is natural to expect that in this industry the use of hard-facing materials is widespread.

The most extensive use of hard-facing is for dipper bucket teeth. The teeth in a 12-yd. dipper bucket were hard-faced by an Indiana coal company. This company reported a life ratio of 7 to 1 for the hard-faced teeth over the ordinary teeth. Other types of excavating buckets such as drag-line buckets and clam shell buckets, dredging cutters and drag scrapers are also very successfully protected from abrasion by the use of hard-facing materials.

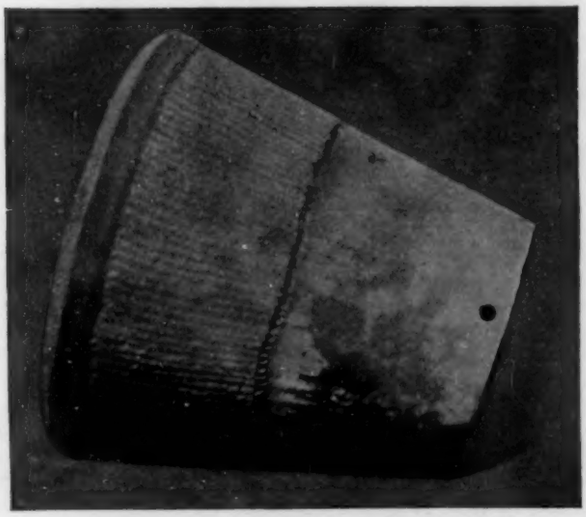


Fig. 6—Twice the Life Is Obtained by Hard-Facing This Gyratory Crusher Mantle

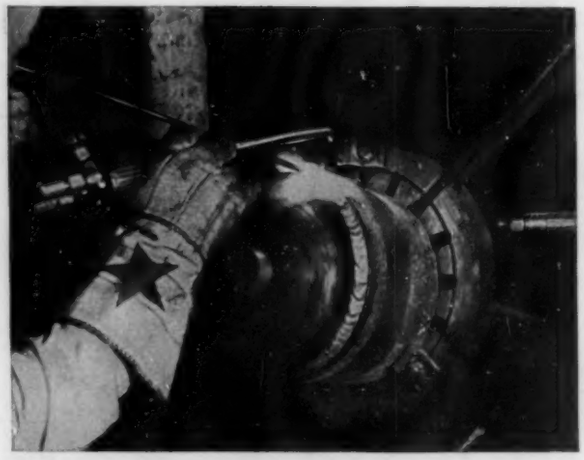


Fig. 7—Haynes Stelliting a 9-In. Valve Disk for High-Temperature, High-Pressure Steam Service

The lumber and paper industries likewise have their problems of abrasion and, while they are not as severe as those encountered in industries in which rock is handled, they are bad enough to warrant the use of special materials to withstand wear.

Shredder knives serve to illustrate the economies that have been effected in this industry by hard-facing. The knives used at an Ohio mill for shredding sulphite board and other pulp materials were formerly made of a high-grade steel and cost $200 per set. A set of worn knives was salvaged from the scrap pile and hard-faced at a cost of $90. This set lasted six months as compared to a life of only one month for a new set of steel knives. Inasmuch as the hard-faced knives were easily rebuilt for many similar periods of service, this resulted in reducing the annual charge on a machine using one set of knives, from $2400 to $180, thereby effecting a saving of more than $2000 in one year.

It is impossible to list here the numerous applications of hard-facing materials and the various types of machinery that are in use today. These several examples will serve to demonstrate the economies that can be effected by proper use of these materials and the increased efficiency that is obtainable thereby. Figure 4 illustrates a hard-faced hot trimming die used by a Michigan forge company. They obtained 6970 pieces from the hard-faced die, while previous to its use a carbon tool steel die averaged only 500 pieces. The manufacturer who submitted these figures estimates a daily saving of $40 on this one application.

Abrasive conditions in the mining industry parallel those encountered in the excavating field, and in many cases the equipment is identical. For example, hard-surfaced undercutter bits cut three to six times more coal per grind than ordinary bits. When coal is being cut it takes two men 10 to 20 min. to change bits in the machine, so that with the hard-faced bits that do not have to be changed as frequently, considerable time is saved for cutting coal, thereby increasing production. Recently tests were run in eight different mines with coal cutting bits hard-faced with tungsten carbide particles held in a steel matrix. These bits showed a minimum increase in life of 25 to 1 over steel bits. In addition to this increase in life there were also substantial savings in time for changing bits and in power consumption.

A large amount of hard-facing material is used in the mining industry for resurfacing gyratory crusher mantles. Experiences of mines which are using equipment protected in this manner indicate that the use of hard-facing

Fig. 8—Hard-Faced Valve Seats for Steam Service Outlast Usual Materials 6 to 10 Times

has resulted in twice the life of equipment at one-quarter of the cost. (Fig. 6.)

In the oil industry, rapid progress has been made within recent years in the development of materials, methods and processes, whereby the efficiency of oil-well drilling tools has been considerably improved. Each step in the transition from plain dressed and tempered bits, to bits hard-faced with non-ferrous alloys and finally to bits hard-set with diamond substitutes, has greatly reduced drilling costs. Less than ten years ago at a certain well in Texas, an average of 84 shop dressed and tempered fishtail bits was required to complete a well. The introduction of the non-ferrous hard-facing material resulted in cutting this requirement to 44 bits; and today wells are drilled through the same formation to the same depth with only 14 bits hard-set with tungsten carbide inserts and then hard-faced with a Composite Rod of tungsten carbide particles and steel matrix. Good tools properly hard-set have enabled drillers to obtain fast, straight, out-to-gage hole with long life between round trips.

For example, a $9^{7}/_{8}$ in. diameter fishtail bit was used at Conroe, Texas. After drilling a total of 2713 ft. of hole the bit was pulled out and measured and it was less than $^{1}/_{16}$ in. out of gage. The same excellent, dependable performance is being shown by hard-faced oil well bits in practically every oil field in the world.

In the power industry hard-facing materials are called upon to withstand not only abrasion but also heat erosion and corrosion. The red hardness and corrosion resistance of non-ferrous alloys make them specially suited for use on valves in high-pressure steam lines and also for turbine blading. In Fig. 7 the hard-facing is applied to a valve disk for high-temperature, high-pressure steam service. Practical applications have already shown that hard-faced valves outlast ordinary valves six to ten times.

The iron and steel industry uses the hard-facing process to protect such parts as coke pusher shoes, water-cooled pokers, coke crusher rolls, electric mud guns, tap hole augers, hot shearing knives, spindles, guides and dozens of similar wearing parts. Hard-facing applications in the brick industry include pug mill knives and pusher shoes, feeder shoes and dies. The aluminum, glass and beet sugar industries have also found many money-saving applications.

As in all types of welding, a very definite procedure has been worked out for applying the various hard-facing materials. Both the iron base materials and the non-ferrous materials may usually be applied by either the electric arc or the oxyacetylene method. For the non-ferrous alloys the oxyacetylene method is usually recommended wherever possible. The blowpipe allows better control over the operation and produces a smoother deposit. Particles of scale and foreign matter are more easily eliminated by this method and the edges and corners can be formed better. In addition, when using the oxyacetylene process, the interalloying of the hard-facing material with the base metal is negligible. For applying the iron base materials both the oxyacetylene and electric methods are widely used.

The procedure for hard-facing steel with a non-ferrous alloy usually consists in bringing a small section of the surface to "sweating" temperature and then allowing the alloy to melt and spread over the sweated area. An excess acetylene flame is used, and it should be adjusted so that the flare or outer cone denoting excess acetylene extends double the length of the inner cone. This is important and must be done to insure a satisfactory job. In the electric arc method the polarity is reversed, making the rod the positive electrode. The current requirements are reasonably heavy.

As the tungsten carbide inserts cannot be applied to wearing surfaces in the same manner as the hard-facing rod, they are usually applied by tacking individual pieces on the wearing surface and then tying them in by covering them with one of the hard-facing alloy rods. This operation, which is called hard-setting, is universally done by the oxyacetylene process. The Composite Rod is also best applied with the oxyacetylene process. The flame should contain a small amount of excess acetylene and the application made without penetrating as deeply into the base metal as in ordinary steel welding.

In many welding operations it is important to design jigs and fixtures to facilitate the welding procedure. Here are shown examples of typical, simple fixtures. Many operations which might not otherwise be possible are rapidly and efficiently accomplished through the use of carefully designed auxiliary appliances.

While hard-facing is used in practically every industry today, the opportunities for further profitable applications are still almost unlimited. Wherever friction is present, wear takes place and there is a potential need for abrasion resistant material which is not only hard at room temperatures but retains its hardness at elevated temperatures. In choosing a hard-facing material it is therefore essential first to select an alloy that remains hard at red heat and second one that is easily applied.

Projection Welding and Power Consumption

By P. W. FASSLER†

JUST recently some important problems have arisen which the writer thinks should be cleared up immediately.

Size of the Projection Welder

How large should the projection welder be built in comparison to the number and size of the embossments, the size and thickness of the material, in relation to the shape of the stampings to be welded? After the many thousands of projection welders, which were put in production in the last eight years, there should not be any question in this respect.

Welding experts of prominence are under the impression that projection welding machines have to be built for a capacity of over 50 kv-a. per spot on $^1/_8$-in. stock. On the other hand, we saw machines in production where only 20 kv-a. are figured for the same purpose. The welding industry has to come to an agreement and set a certain normal or standard so, at least, there will be some uniformity, which would make it easier for the user to buy the proper welding equipment.

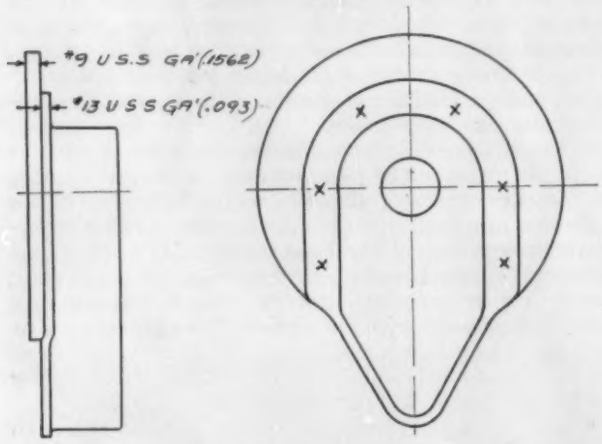


FIG. 1

In a comparison between spot welding and projection welding, we made a statement in the May 1931 issue of this magazine that it takes approximately 175 kw. for eight spots on $^3/_{16}$-in. stock or about 22 kw. per spot on straight or flat parts. These welds are done in an experimental department with relatively long welding time and low pressure. Higher pressure and shorter welding time, of course, would increase this figure considerably.

Tests made later on production jobs with an oscillograph on a similar job, as Fig. 1 shows, where the welding machine was not under such careful observation as in experimental welding, 40 kv-a. or $40 \times 0.32 = 12$ kw., were used per spot. The machine this reading was taken from had a power factor of 32%. But there are a large number of machines in production with over 50% power factor which, of course, gives us an entirely different picture, as we analyze later on.

We have to bear in mind that the success of the projection-welding machines depends on two distinct factors, since the mechanical part has the same significance as the electrical part, as is explained in the following.

Mechanical Part

In the May 1932 issue of this magazine, the writer explained, from different sketches and diagrams, the mechanical operation. Since then hundreds of machines were built with all this experience and nothing has changed in this assertion. The embossments are the same as described; pressure application is the same. For a better understanding, we repeat here, in Figs. 2, 3 and 4, different stages of this process. In Fig. 3 there is still space left for the final upsetting which is accomplished without current; only heavy pressure is necessary

† Consulting Welding Engineer.

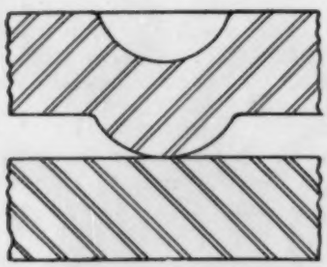


Fig. 2—Original Embossment after Initial Pressure Is Applied and before Weld Is Started—Light Spring

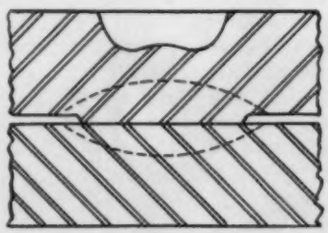


Fig. 3—End of Weld with Intermediate Pressure —Light Spring

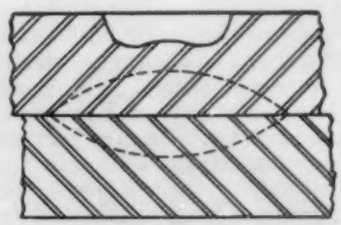
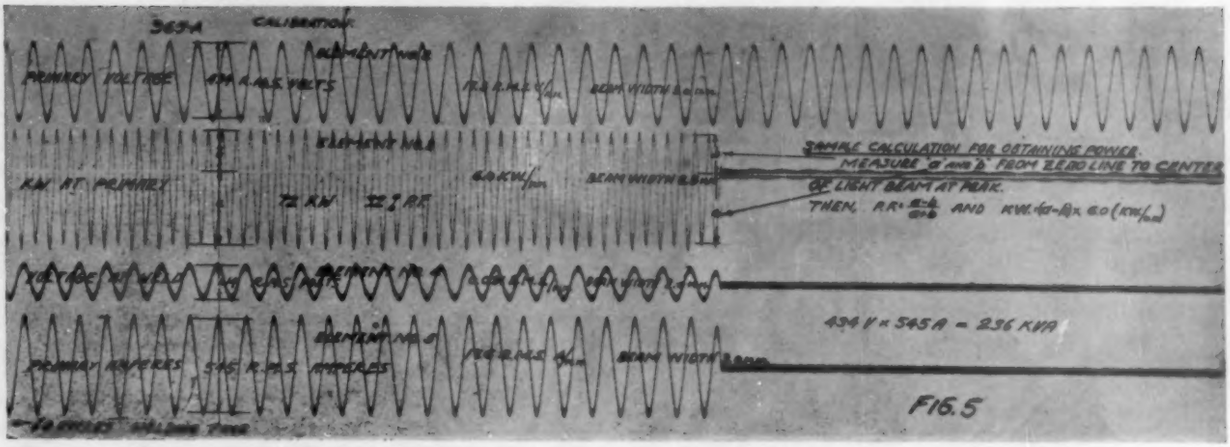


Fig. 4—Weld after Upsetting—Heavy Spring


SAMPLE CALCULATION FOR OBTAINING POWER.
MEASURE a AND b FROM ZERO LINE TO CENTER
OF LIGHT BEAM AT PEAK.
434 V × 545 A = 236 KVA
F16.5

while the material is still hot, as Fig. 4 shows. From the electrical phenomena of this process, we will discuss in the following one of the most neglected—that is, the Power Factor.

Electrical

The reproduced oscillogram, Fig. 5, explains what happened during the entire welding cycle, welding the part shown in Fig. 1. The top curve shows a voltage of 434 volts and the bottom curve, 545 amps. These same curves also indicate that 60 cycles or one second was used as welding time. The power factor is determined as explained in the center curve, which is the watt curve, and found to be 32%.

The power factor or cos. can, as it is well known, also be determined in dividing kilowatts by the kilovolt amperes. In determining the number of kv-a. used per spot we have to divide 236 by 6 = 40 kv-a. With a higher power factor, for instance 52%, we see how conditions could be improved, namely, $72 \times \frac{1}{0.52} = 145$ kv-a., in this case we need only $\frac{145}{6} = 24$ kv-a. per spot. With this power factor a much lighter machine could have been built and accomplished the same result.

We know that we have in our hands to create any projection weld and increase or decrease the power consumption per spot through mechanical and electrical means. On more complicated stampings, or heavier stock, where the embossments have to be oversized, or when other conditions occur, there is still a way to control these welds.

Our friends, who, no doubt, are very much interested in these statements, will tell us that the oscillograph is not giving us the true story. The writer, who had some experience in this respect a few years ago, advocated and supported this point of view to a certain extent, but since we learned more about how to take and read these oscillograms, especially in welding, we are sure that they are as true as any photograph. The great influence the power factor plays in the entire resistance-welding industry, is not yet fully appreciated. Therefore it may be advisable to abandon, for a while, our policy to debate only practical happenings in our industry, and try to compare and analyze these oscillograms from a theoretical point of view.

We take, for instance, the machine with a cos. of 0.32 which was dealt with in our oscillogram and compare it with a better built machine with a power factor or cos. of 0.52.

This is by no means a theoretical assumption as there are a great number of machines in operation with power factors up to 0.55. However, we also find machines with a power factor of only 0.27.

In our voltage vector diagram (Fig. 6), the line AB represents the secondary voltage of the transformer which is six volts in this case.

The power factor or cos., 0.32, corresponds to an angle of $71\frac{1}{2}$ deg. according to the table of trigonometric functions. This angle represents the difference in phase between voltage and amperage.

The line AC represents the drop in voltage due to the resistance in ohms of the entire secondary circuit and is in phase with the amperage. Obviously the greatest percentage of this drop will occur in the work itself.

The line BC represents the drop of voltage due to magnetic reactance.

An entirely different diagram can be drawn for the machine with the higher power factor of 0.52. This diagram is shown in dotted lines. The angle reduces to $58\frac{1}{2}$ deg. and the voltage available for the work increases from AC to AD in a ratio of approximately 1.6. The drop of voltage due to magnetic reactance reduces correspondingly.

The drop in voltage due to the resistance can be expressed by the current in amperes multiplied by the resistance in ohms, and since that resistance does not change appreciably, it is obvious that the current must increase to satisfy the relation.

A machine built for the same voltage but constructed with low reactance as to allow for a power factor of 0.52 could, therefore, deliver 1.6 times more amperage or else

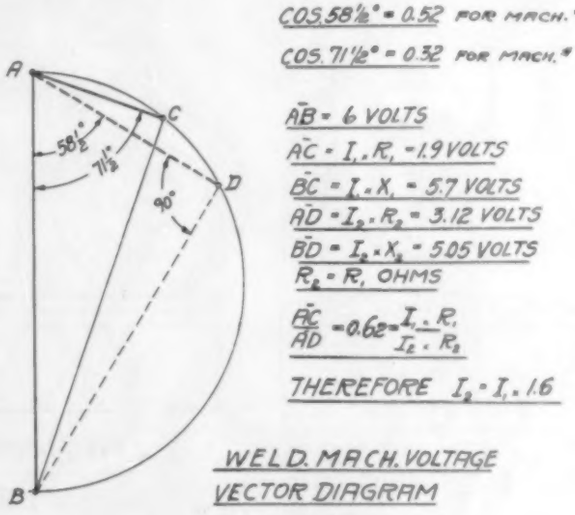

COS. 58½° = 0.52 FOR MACH. #2
COS. 71½° = 0.32 FOR MACH. # 1
AB = 6 VOLTS
AC = I₁ · R₁ = 1.9 VOLTS
BC = I₁ · X₁ = 5.7 VOLTS
AD = I₂ · R₂ = 3.12 VOLTS
BD = I₂ · X₂ = 5.05 VOLTS
R₂ = R₁ OHMS
AC/AD = 0.62 = I₁ · R₁ / I₂ · R₂
THEREFORE I₂ = I₁ · 1.6
A
B
C
D
58½°
71½°
90°
WELD. MACH. VOLTAGE
VECTOR DIAGRAM

Fig. 6

it would be possible to build such a machine of lower kv-a. rating and deliver the same amperage.

We agree with the welding machine builder that it is advisable in many cases to oversize projection welding machines, if it be only for the reason that it would be advisable to have power in reserve which enables the welding machine user to add more embossments or use the machine for a larger job, as is happening quite frequently.

This, of course, is to be decided by the welding machine user who can in most cases afford a larger machine, since the welding machine builder asks only .17 to .20¢ a lb. in the present price-cutting period. However, the buyer should bear in mind the fact that the power factor of a welding machine influences the total power factor of the whole plant.

Not only the power supplier's but also every plant manager's aim is to obtain the highest possible power factor in the plant, as this is very important for the buyer in purchasing the current and the agreement he has to make with the power plant. On the other hand, it has already happened that plants with a too low power factor face serious difficulties and much money has been spent to rearrange plants in order to reach a high power factor.

In the past, too much stress has been placed on improving power factor chiefly among minor equipment not concerned with welding, namely, motors, generators and other synchronous devices. The power factor of welding machines was neglected due to the fact that in the beginning of the welding machine industry much smaller welding equipment was put in production. Naturally, machines of small size with relatively longer welding cycles would not require such attention and did not affect the supply line as the larger welding machines of today, especially projection and flash welders which absorb up to thousands of kv-a. in a very short welding cycle, or less than one second.

The consumer has been, for some time, dissatisfied with the welding machines offered. These welding machines have undoubtedly been responsible for much of the unsatisfactory power supply conditions. It now seems to be the proper time to call attention to the correct cause of much of the trouble by increasing the power factor of welding machines.

Resistance Seam Welding Automobile Gas Tanks

By RAY APPLEGATE†

IN ONE of the larger automobile manufacturing companies the terne-plated gasoline tanks were being made by lock seams and then soldering the resulting joints.

† Electrical Welding Engineer, P. W. Fassler & Company.

While this had been accepted by most builders of this type of containers as a satisfactory method because of lack of knowledge of any other way to finally assemble them, a growing feeling of a need of a different method was noticed and as this firm had recently acquired man-

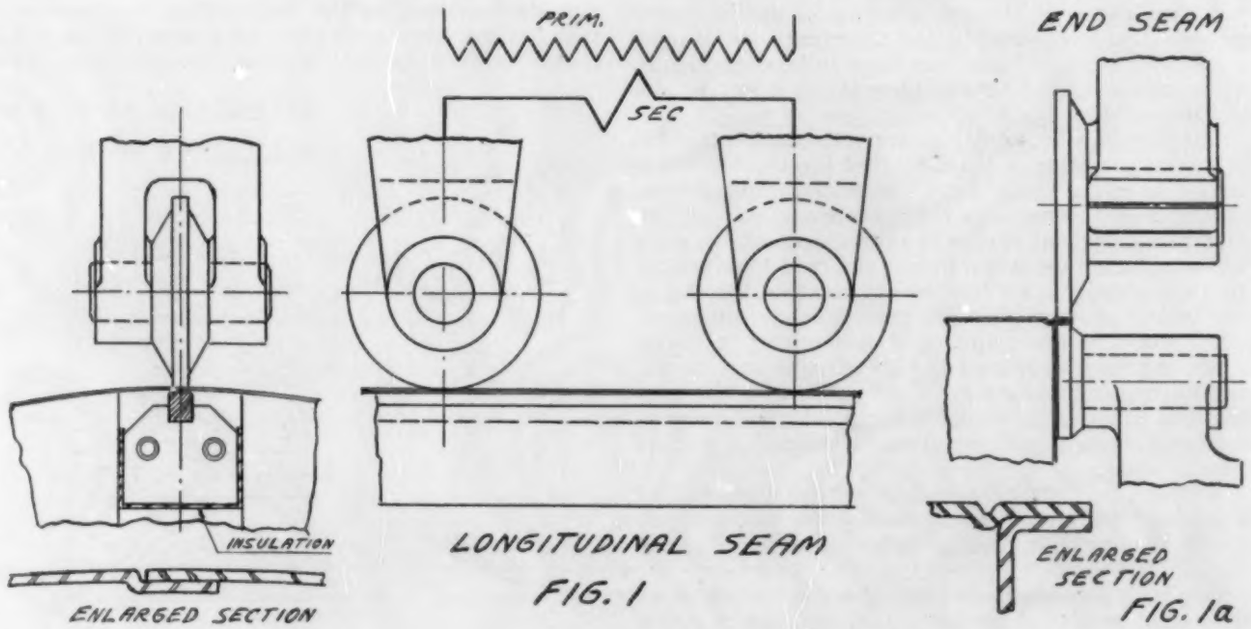


FIG. 1

FIG. 1a

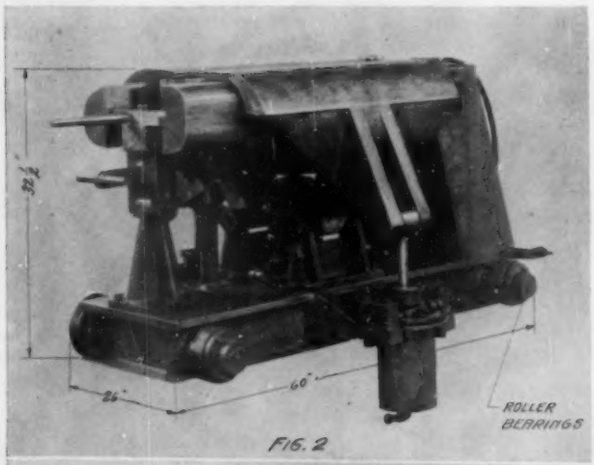


FIG. 2

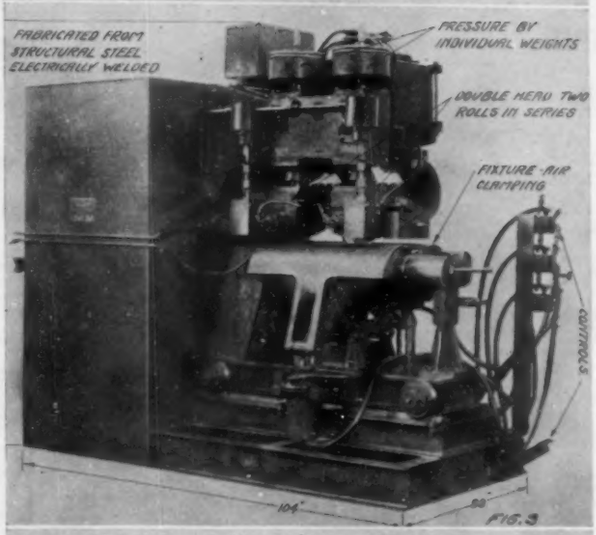


FIG. 3

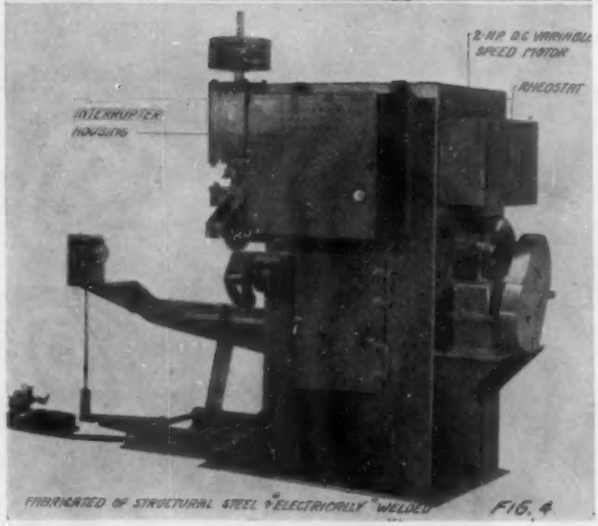


FIG. 4

agement who were welding minded this new method was suggested as a means of assembly.

Many objections were raised by those interested in the original way of seaming the tanks but inasmuch as the largest users of auto gasoline tanks were welding their tanks by the resistance method these objections were overruled and plans were laid to properly design and arrange for proper machinery to resistance weld the tanks.

The engineering department redesigned the construction to suit the conditions made necessary and followed such suggestions offered that were deemed advisable, thus making the preliminary work much easier. Any other changes of design and manufacture that occurred were made necessary by minor difficulties which would show up from time to time. The writer, who was in charge of this new development, had previously gathered valuable experience in another automobile concern where gas tanks were welded from the same material. On this new tank, however, the longitudinal seam presented a new and interesting problem. A parallel rolled seam welding process, where the lower roller was one pole and the upper roller the other pole, would not do because the arm length would have been excessive and the whole design of the machine would have been much heavier and higher in price. Not only that, the tanks would have to be tacked by special spot-welding operation before the seam-welding operations.

He suggested using the series welding method whereby two rollers were mounted on the upper arm, the transformer placed close to the rollers and the length of the secondary circuit materially decreased as the side view in Fig. 1 shows. A ground bar of copper and Elkonite was used as a bridge for the welding current. The rollers were made of a copper cadmium alloy from the beginning. With this arrangement another very important advantage could be reached, namely, the welding time could be decreased and production naturally increased, as each roller had only half of the length of the gasoline tank to weld.

The following is a description of the mechanical features of these welders, which included many ingenius ones worked out by the builder: each clamping fixture made like the one shown in Fig. 2 was interchangeable with the others made necessary by the different sized tanks, an acme screw shaft from the back and fitted into a nut held by two screws which was all the work needed to change fixtures except air lines which were of the quick acting snap type. When changing fixtures a dolly truck with track similar to track on a welder was run up to the machine and loaded where it was wheeled to a rack made to hold all spares. These fixtures were of steel arc-weld construction with bronze clamping arms.

A reversing mechanism at the rear operated the fixture in and out and returned it to starting position; air clamps were operated by hand as shown in Fig. 3. The current for this machine was interrupted by a synchronous mechanical device which was selected largely because of the lower price compared to the tube timer auto transformer type and, while it required considerable servicing, it became a dependable unit although the writer would advise the use of the tube timer type if such could be secured. The baffle plates on these tanks were spot welded in place. The ends were made like sketch Fig. 1*A* shows, and were seam welded in place after being pressed in place by an assembly fixture which put both heads in at the same time.

The roller seam welder that was used on this operation was of a conventional type and was equipped with a roller rest apparatus and rolled around very easily as shown in Fig. 4. A speed of 84 in. a minute was reached on the complete set-up and the few leaks resulting were usually at the ends of the longitudinal weld where it crossed over the weld on the heads.

At this plant the original soldering operation was done manually on wooden soldering blocks. It was true that they had an unusually higher number of leaks compared to the automatic methods used in higher production plants today. Because of this a large saving was made by the welded tanks as the solder usage was rather high

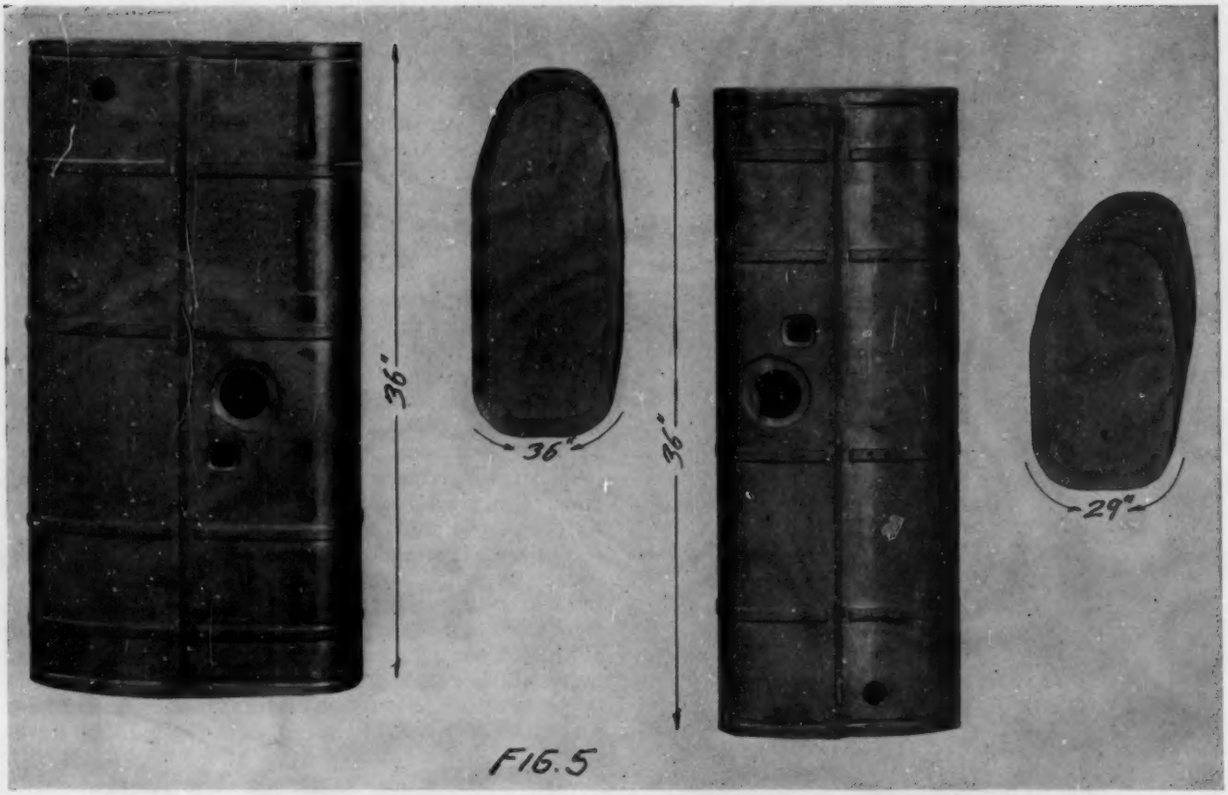


FIG. 5

due to the hand operation. The few leaks were of a pinhole nature and were quickly repaired by the tester who, after testing in a water tank under fifteen pounds air pressure, would clean with acid and put on a drop of solder which was always sufficient to close the hole.

Tests of this method show that tanks welded by seam welding were of equal rugged construction as the lock seam type and immersed in brine and exposed to air did not rust at the weld any sooner than at other points where the plating was broken by the press operation. Construction of the tank is shown in Fig. 5. However, this is but one of several types of construction to which this type of welding has been adapted.

Gasoline tanks constructed in this manner had advantages over drawn tanks as they were made with a very small loss due to scrap because they were simply embossed and were not deep drawn as is necessary in a tank made of two halves.

These tanks were made of single pass terne plate of No. 18 gage low-carbon steel and were wrapped after forming in a press using a progressive die; thus, they were completely formed before reaching the seam welder.

The machine with the double rolls welding the longitudinal seam was of 150 kv-a. capacity and the machine on the end seams was of 100 kv-a. capacity.

Referring to Fig. 6 it will be seen that the duty cycle of the horizontal welder is five cycles on and three off. Other characteristics are plainly shown on the oscillograms.

In Fig. 7 the duty cycle is slightly different, being four on and two off due to an increase in speed on this job because of a longer total of linear welding footage.

Fig. 6

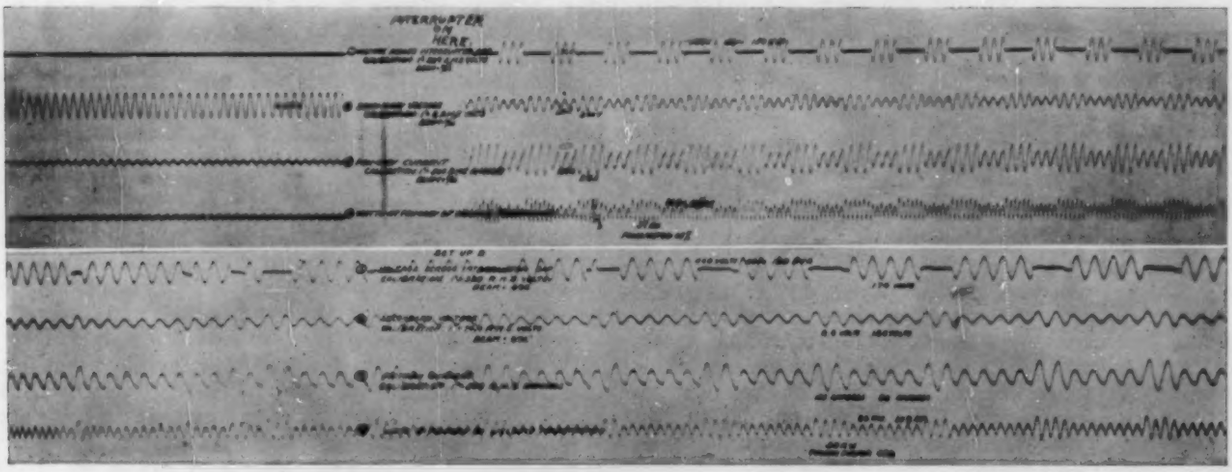


Fig. 7

Thyratron Tube Control of High Speed Resistance Welders

By WARREN C. HUTCHINS† and O. W. LIVINGSTON††

APPLICATION of electronic tubes to the control of industrial apparatus has improved the operation of many existing devices and made possible many others heretofore impossible with conventional method of control. This article describes the very interesting application of Thyratron tubes to resistance spot-welding machines.

Spot welding is used to unite the surfaces of two or more sheets of metal. The parts to be welded are clamped between two electrodes, and the electrical resistance of the two surfaces to be joined is sufficient to create a welding temperature when current of very high density is passed through the work.

It is, therefore, necessary to use copper electrodes or some alloy such as Elkonite to minimize the resistance at the point of contact between the electrode and the work. Relatively high resistance at this location would cause objectionable heating, thereby burning the electrode tips and the outer surface of the work.

The time required to make a weld depends upon the density of the current. For instance, two $^1/_{32}$-in. sheets of mild steel can be welded in $^7/_{10}$ths of a second with a current density of 250,000 amps. per sq. in., and $^1/_{60}$th of a second with a current density of approximately 940,000 amps. per sq. in. These values are based on test welds approximately $^3/_{16}$ in. in diameter. These high currents are delivered by welder transformers with low voltage secondary.

The usual method of welding is with the longer time of current application (0.5 to 1.0 second). If the welding time is one second and an equal time is required for lifting the electrode from the work and placing new work in the machine to be welded, the maximum production speed will be 30 spot welds per minute. This speed was considered excellent for many years, but does not meet the high speed requirements of modern production.

† Industrial Engineering Department, General Electric Co.
†† Vacuum Tube Engineering Department, General Electric Company.

Fig. 1—Cross-Section Micrographs of Spot Weld on Two Sheets of 0.037 Annealed Stainless Steel (18–8). Weld Area Magnified 50 diam.

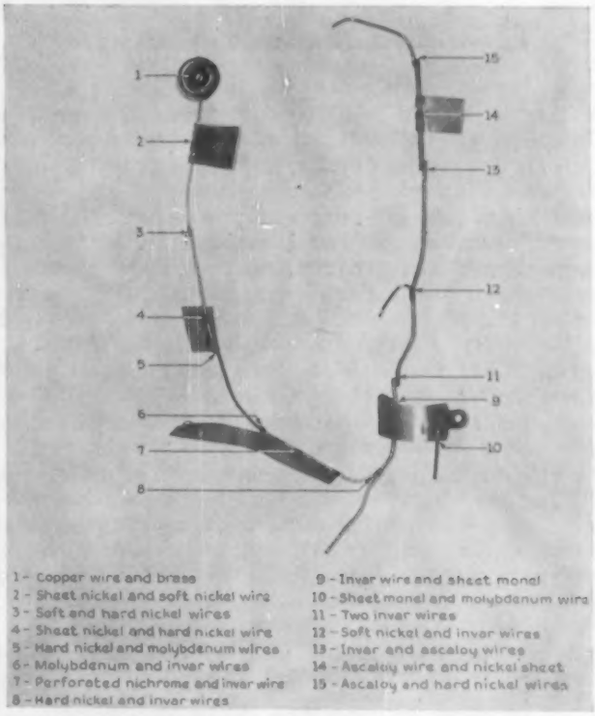

1 - Copper wire and brass
2 - Sheet nickel and soft nickel wire
3 - Soft and hard nickel wires
4 - Sheet nickel and hard nickel wire
5 - Hard nickel and molybdenum wires
6 - Molybdenum and invar wires
7 - Perforated nichrome and invar wire
8 - Hard nickel and invar wires
9 - Invar wire and sheet monel
10 - Sheet monel and molybdenum wire
11 - Two invar wires
12 - Soft nickel and invar wires
13 - Invar and ascaloy wires
14 - Ascaloy wire and nickel sheet
15 - Ascaloy and hard nickel wires

Fig. 2—Welds Made with Thyratron Control of Various Metals

For consistent welds it is necessary to maintain accurate timing of current application for each weld. Usually an accuracy within plus or minus 10 per cent will produce consistent welds. The variation in time required for the conventional contactor to close and open is usually from two to four cycles of a 60-cycle power supply. In addition, the variation of the control switch for the contactor coil may be two cycles or more. Assuming four cycles to be the maximum variation in the contactor, plus two cycles variation in the timing of the contactor coil current, the total variation may be six cycles, or plus or minus three cycles. If three cycles are 10 per cent variation from the desired time, the total welding time will be 30 cycles minimum, or $^1/_2$ second. It is, therefore, impractical to use the conventional contactors for shorter welding periods than this. Specially designed contactors may be used for shorter times than $^1/_2$ second, but for extremely short times even they will not give entirely satisfactory results. There are several main reasons why it is desirable to make the weld in much shorter periods. They are:

First, to increase speed of welding.

Second, to reduce oxidation of outer surfaces. When

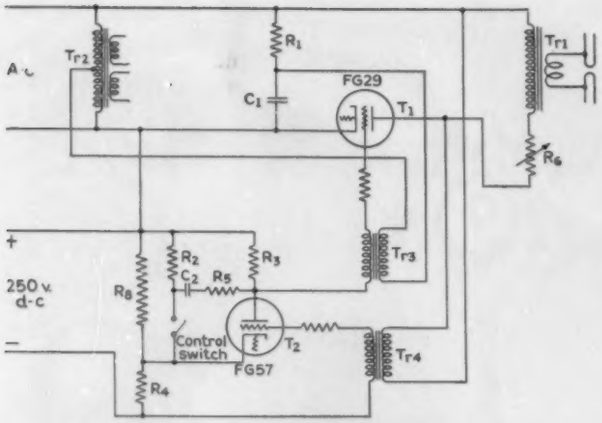


Fig. 3—Schematic Circuit of Half-Cycle Thyratron Welder Control

welding is done in relatively long times, the surface of the metal will be badly oxidized. When current is on for only one or two cycles, there will probably be no oxidation (Fig. 1).

Third, to prevent unnecessary warping. When the time of current application is relatively long, the higher temperatures extend over a large area, causing buckling or warping of the metal. If the time of current application is extremely short, the temperature gradient will be very steep and minimum of warping will result.

Fourth, to permit welding of some unusual alloys. When welding special alloys, such as stainless steel and aluminum, it is absolutely necessary to keep the welding time very short in making a satisfactory weld.

Fifth, to increase life of electrode tips. With long welding periods, the metal next to the electrodes becomes sufficiently hot to burn or distort the electrodes. When spot welding is done in short enough time, the heat is maintained between the two outer surfaces of the work, preventing the heating of the electrode (Fig. 1).

A very accurate control device for short periods is therefore desirable; a control adjustable to an exact number of cycles with a range of one to ten cycles of 60-cycle power supply will usually accomplish all that is necessary in making satisfactory welds, and insures the realization of the above-listed advantages.

Fairly satisfactory results have been obtained by use of synchronous motor-driven cam-operated switches. The motor-driven cam actually forces the control switch through a complete cycle of closing and opening, producing accurate timing. Arcing at the tips and mechanical difficulties, however, limit its application.

Thyratron tube control has been applied to this application, as well as to intermittent seam welding, and has proved very satisfactory.

Experience has shown that for welding very thin metal sheets a time of less than one cycle of the power supply is desirable. This has led to the development of a welder control suitable for one-half cycle or less. The application of this control to a suitable resistance welding machine has resulted in satisfactory welds being produced on many different alloys, some of which are illustrated in Fig. 2. In addition to those shown, nickel silver and also gold optical frames have been welded. Copper parts can be satisfactorily spot welded, provided their surfaces are tinned in order to create sufficient resistance between the two sheets. It has been found practical to weld copper wire to nickel wire without any artificial resistance.

The essentials of the half-cycle Thyratron welder control circuit are shown schematically in Fig. 3.

In the circuit, Thyratron T1 replaces the contactor, and Thyratron T2 controls the grid of Thyratron T1. In the "off" position Thyratron T2 is conducting, and the D.C. negative bias on Thyratron T1 is equal to the voltage drop across resistor R3. An A.C. bias, leading by approximately 160 deg. and supplied by transformer Tr3 from the phase-shifting circuit composed of capacitor C1, resistor R1 and the primary center tap of transformer Tr2, is also impressed on the grid of Thyratron T1. This bias has no function in the "off" position. With Thyratron T2 conducting and the control switch open, the capacitor C2 is charged through resistors R2, R5 and Thyratron T2 to a voltage approximately equal to the voltage across R3 and of a polarity such that the terminal connected to the anode of Thyratron T2 through resistor R5 is negative. Closing the control switch to make a weld connects the positively charged terminal of capacitor C2 to the cathode of Thyratron T2, and the anode of Thyratron T2 is drawn negative for a time long enough to commutate this tube. Capacitor C2 then discharges through resistors R5 and R3 and recharges through these resistors to the reverse polarity. When C2 has become very nearly charged to this new polarity the voltage drop across R3 is low and thus Thyratron T1 has practically no D.C. bias. As the D.C. bias approaches zero, a condition is finally reached as shown in Fig. 4. Curve *A* represents the anode voltage of Thyratron T1, curve *B* the A.C. grid voltage and curve *C* the critical grid voltage. With zero D.C. bias the curves show that, since the A.C. grid voltage leads the anode voltages by 160 deg., there is only a 24-deg. firing angle. This means that, if the D.C. bias is sufficient to hold Thyratron T1 off for the first 24 deg. of the positive half-cycle, the Thyratron will not "fire," even though the D.C. bias drops to zero immediately afterward, until the beginning of the next positive half-cycle. The Thyratron T1 then carries current for practically the full half-cycle or not at all. (If it is desired to have the firing angle smaller, the A.C. grid voltage may be increased and the phase of this voltage advanced until it is within a few degrees of 180 deg. leading.) The firing of Thyratron T1 excites the primary of the welder transformer and refires Thyratron T2 by the voltage impressed on the grid of Thyratron T2 through transformer Tr4, biasing T1 off before the start of the next positive half-cycle. Opening the control switch allows capacitor C2 to recharge to the correct polarity for commutation of Thyratron T2 upon closing this switch

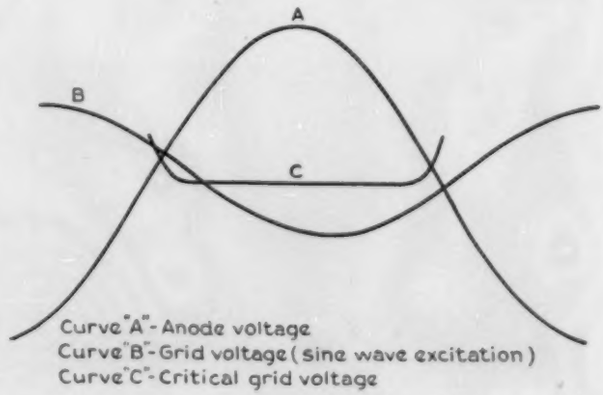


Fig. 4—Voltages of Half-Cycle Thyratron Welder Control

for making the next weld. The current flowing during the welding period may be set by variable resistor R6.

If it is desired to weld in periods adjustable to less than one-half cycle, it is necessary to shift the phase of the excitation of the Thyratron T1 by varying either R1 or C1.

Welding speeds of 600 spots per minute have already been realized with Thyratron tube control, and it is expected that this figure may be materially increased in the near future.

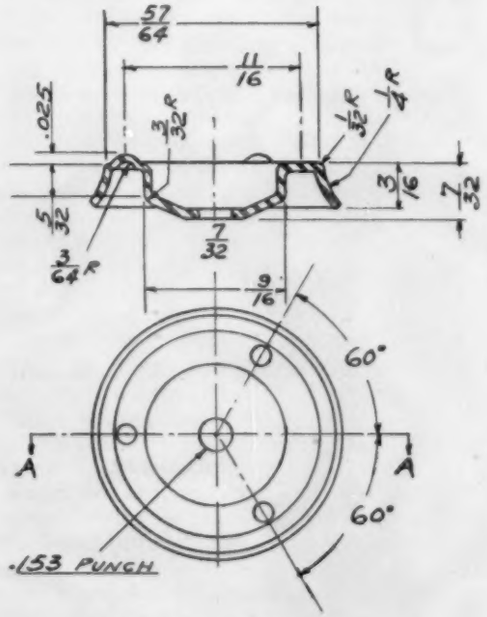
Special Wheel Welder for Toy Trucks

By CHAS. E. SHEARER†

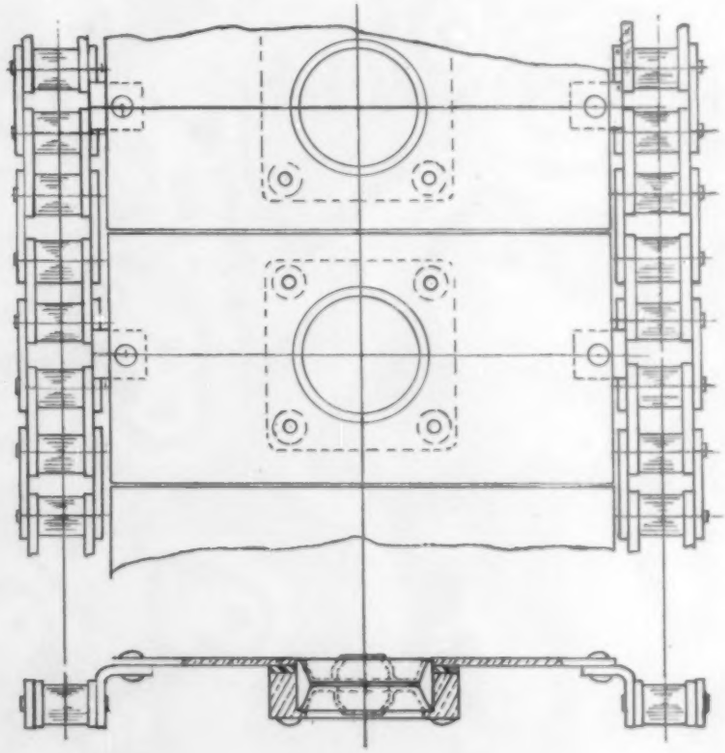
THE Metalcraft Corp. of St. Louis, Missouri, was confronted with the problem of producing 8000 toy trucks every eight hours for the holiday trade, and they were desirous of producing at least 35,000 toy truck wheels each shift on one single welding machine. They had been able to produce by a clinching method 1600 wheels per hour but this was not fast enough for their big order and this problem was presented to our Company whose engineers designed the special machine illustrated in Fig. 2.

Our company supplied for this work one of their standard twin toggle-operated press-type automatic spot welders equipped with a 104 station conveyor mechanism especially designed to receive metal discs to be projection welded together to form the toy truck wheel. This equipment was installed in the early Fall of 1933 and has been operating continuously ever since, producing 4800 welded wheels per hour.

† Secretary, National Electric Welding Machines Company.



WHEEL DISC.
MAT. - STEEL
STOCK - #20 GA. (.0375)
SCALE - TWICE SIZE



SECTION THRU CONVEYOR CHAIN WITH WHEEL DISCS IN WELDING POSITION

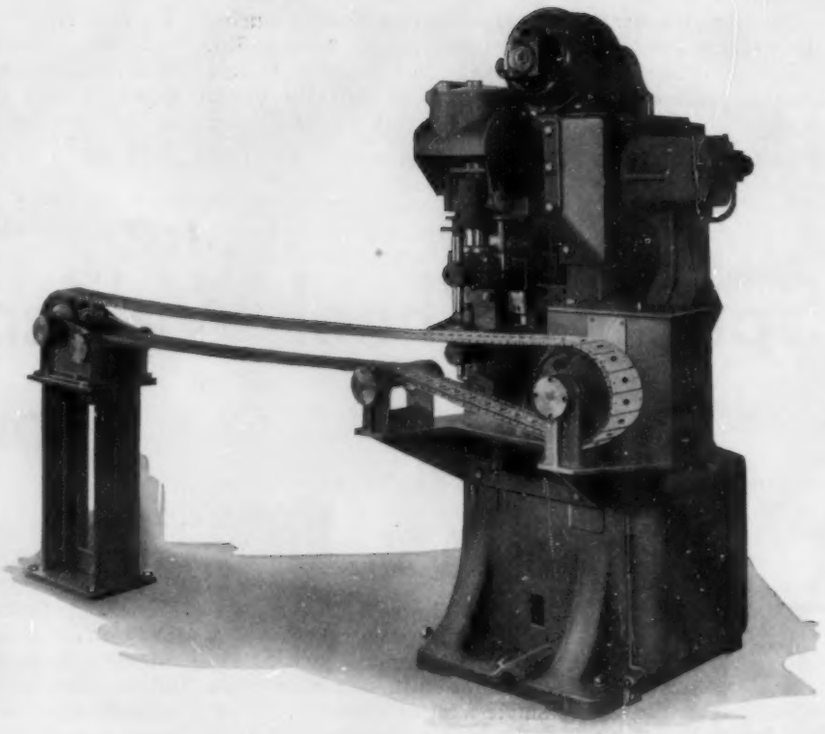
Fig. 1

The illustration shows the welding equipment before it left the manufacturers' factory and the purchaser-built feeding tables on either side of the conveyor where two girls were employed to feed the discs into the conveyor. One girl placed the bottom half in the proper receptacle in the conveyor belt and the other girl inserted the top half in place; the conveyor belt being actuated by the mechanism that operated the welder proper in perfect synchronization enabled the machine to be run continuously at this unusually high rate of production.

Figure 1 illustrates the details of this particular job. The thickness of stock, the kind of stock and exactly how the pieces are formed is clearly indicated in this sketch.

The actual welding is accomplished on a machine powered with a 75 kv-a. water cooled transformer and only a low setting of the heat regulator is necessary. At about 5 volts the secondary amperage of approximately 8000 is used. Approximately 800-lb. welding pressure is being utilized on this particular job.

The necessary jigs are clearly indicated in the sketch which shows a cross section of the conveyor belt.

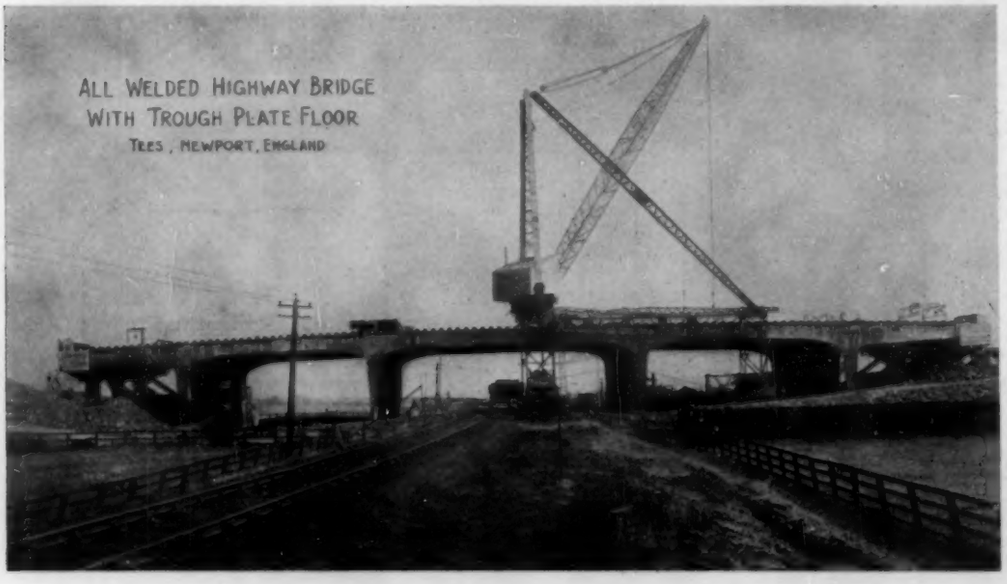


2

Tees (Newport) Bridge

Joint between Girder and Stanchion Leg

Welding seams between flange plates and webs were completed as far as possible in the shops. The temporary cleats were tack-welded to the flange plates, great care being taken to ensure that, when set up in the field, the clearance would be as on the drawing. Two runs in each flange butt joint were executed, the bolts withdrawn from the cleats and the cleats were then knocked off. The flange butt joints were then completed, and the seams connecting the girder web to the 10 x $^{3}/_{4}$-in. plate on top of the stanchion web were run. The clearance of $^{1}/_{16}$ in. at the web joint was arrived at after experimenting with a full-sized model of the joint.



See Frontispiece for Other Photographs of This Bridge

(Courtesy British Steelwork Association)

The Place of Welding in Engineering Education*

By J. H. ZIMMERMAN†

THE status of welding in most engineering curricula is not well defined, and very largely for this reason the average engineering graduate is woefully unprepared to meet the many applications of the various welding processes in his early industrial contacts. The existence of a certain lag between industrial engineering practice and engineering instruction is inevitable but, in the opinion of many, the colleges have been unduly negligent in permitting the development of such a large gap between welding in industry and welding in engineering education. In recent readjustments of the subject matter of the Metals Laboratory courses at the Massachusetts Institute of Technology an attempt has been made to minimize this gap. It is understood that similar readjustments are being made at other institutions and with the belief that the members of the AMERICAN WELDING SOCIETY may be interested in knowing of these changes this note is presented.

Until recently welding has been squeezed into or tacked onto some existing course of instruction, usually one of the shop laboratory courses. Or, possibly, it has been offered in a small way as an optional course. It has, in other words, been considered as a secondary process, one not sufficiently strong to stand on its own feet. This is entirely wrong and for evidence one has but to refer to the many modern applications of the process in manufacturing and construction.

Granting, then, that welding should be established to stand up alone as a distinct entity among the shop laboratory courses the problem of the mechanics of this change presents itself. Assuming that a fixed percentage of the curriculum time is available for shop courses and that these courses include the usual work in pattern making, foundry, forging and machining, the problem resolves itself into the relatively simple matter of deciding what part of the existing schedule must be deleted in order to give welding its deserved percentage of the total available time.

The first inclination is to take some time for welding away from forging. This thought is natural and is based on the theory that hand forging as a process is decidedly passé. However, from another angle, assume that the title and content of the forging course be changed to include the hot and cold working of metals in general. Assume that the forces and anvils have given way to drop hammers, forging machines, punch presses and similar equipment to be used as a basis for fundamental instruction in forming, drawing, rolling, swaging, upsetting, extruding and in all possible basic hot- and cold-working processes. Certainly all time now generally devoted to the old hand-forge work can be utilized advantageously as outlined above and sacrifice of any of this time for welding would be wrong.

Another logical source of time for welding may be the foundry. It is agreed that many changes in manufacturing procedure involving the substitution of fabricated members for castings have been made and that there will be more of these changes in the future. Again from the other angle, however, are the many recently developed special purpose alloys, stainless materials, high test irons, die castings, permanent molding and new molding machinery, instruction in all of which should be more than ample to take the place of an obvious cut in the time now devoted to gray cast iron and the cupola. Motor manufacturers have recently effected economies by the substitution of castings for forged cam and crankshafts. Startling developments have been made in the centrifugal casting of metals. Summing up the foundry picture one finds need for much change in the existing subject matter for a proper course but any shortening of the time now employed does not seem justified. Again, no progress has been made toward the establishment of curriculum time for welding.

It is even more simple than in the cases of the forge and the foundry to justify the maintenance of all possible time for instruction in machine tool work. The only remaining possibility is the elimination of work in pattern making.

Pattern making as generally offered in colleges does not differ a great deal from the wood-working or manual-training courses offered in preparatory schools. It is essentially a "sand-pile" course, that is, one in which the student is not required to think, in which he finds relaxation through pleasant work with his hands. The existence of courses of this type in an engineering circulum has, however, often been questioned. As far as essentials of pattern design are concerned, it is believed that contact with patterns in the foundry together with lectures and demonstrations of the principles of pattern design in this same course should suffice. Taking all things into consideration it appears obvious that if welding is to come, pattern making must go. At the Massachusetts Institute of Technology both the time and space formerly occupied by pattern work are now taken up by work in welding and all engineering students who normally take shop laboratory work will be required to pass a course in the Welding Laboratory.

Having thus established a place for welding, problem two immediately presents itself, namely, what should be included in this course? In the first place the purpose of this work should not be to make a finished welder out of each student. In this sense the welding instruction to be given in a four-year engineering course should not be confused with trade-school instruction in this subject. It is believed that the manipulation of welding apparatus

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† Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology.

Table 1—An Estimate of the Distribution of Engineering Effort as Applied to Welding and Allied Processes in Industry

I. Plastic Welding

(1)	Butt Welding	11%
(2)	Flash Welding	6%
(3)	Spot Welding	5%
(4)	Seam Welding	3%
(5)	Projection Welding	2%
(6)	Resistance Welding Total (1)–(5) inc	27%
(7)	Thermite Pressure Welding	1%
(8)	Plastic Welding Total (6) and (7)	28%

II. Fusion Welding

(9)	Metallic Arc Welding—D.C.	12%
(10)	Metallic Arc Welding—A.C.	13%
(11)	Metallic Arc Welding Total (9) and (10)	25%
(12)	Carbon Arc Welding	6%
(13)	Arc Welding Total (11) and (12)	31%
(14)	Gas Torch Welding	14%
(15)	Atomic Hydrogen Welding	4%
(16)	Thermite Fusion Welding	4%
(17)	Fusion Welding Total (13)–(16) inc	53%

III. Allied Flame Processes

(18)	Flame Cutting	12%
(19)	Flame Machining	3%
(20)	Localized Flame Heat Treating	4%
(21)	Allied Flame Processes Total (18)–(20) inc	19%
	Grand Total, (8), (17) and (21)	100%

should be considered as an entirely secondary part of a proper course for engineers. The primary purpose of the instruction should be thoroughly to appraise the student of all the potentialities and possibilities of the various welding and allied processes. He should be given a groundwork for designing for welding, he should be taught to consider welding as a thoroughly useful engineering tool and he must be equipped to use this tool intelligently.

With the establishment of the time and place for fundamental instruction in welding and allied processes the next problem is the arrangement or organization of this time in order that the student may be given a complete and properly proportioned picture. To some extent the institution must, of course, adapt its instruction to its equipment but this should be a strictly temporary or transition procedure. The real basis for the division of time between the various processes should be the extent to which each is important industrially. In other words, engineering instruction should as nearly as possible parallel engineering effort in industry in this instance. It is, of course, possible for the instructor to estimate this division of effort through his contacts with industrial welding and the literature, but it is doubtful if any two estimates of this nature will be in entire agreement.

In order to obtain a composite opinion on this subject a questionnaire has been submitted to the members in attendance at the Fall Meeting of the AMERICAN WELDING SOCIETY and the results of this inquiry are averaged above in Table 1.

Instruction in welding should not stop with this elementary or orientation course for all engineering students, but continuations should be made in the more specialized aspects of the various branches of engineering.

The student of civil engineering or building construction must, of course, be thoroughly instructed in the elements of joint design. Comparative designs for riveted and welded structures should be studied.

The mechanical engineer must also be familiarized with the principles of joint design but his real interest lies primarily in the applications of welding in manufacturing, particularly in the automotive field, in the design and construction of pressure vessels, etc. As a fulfillment of this need, in addition to the incorporation of welding in the machine design and production methods courses, a continuation course in Welding Engineering and Application should be offered. Here, specialized processes, costs, etc., may be considered more completely than in a preliminary laboratory course.

Consider next the metallurgical engineering student. Certainly the industrial metallurgist of today must know his welding thoroughly. There is no single process involving any more metallurgy than welding. In order to properly equip its graduates in this respect the Institute has and will continue to offer to its student metallurgists and others a course in the Metallurgy of Welds.

Finally appears the matter of student thesis and research work in welding. The subject material for such investigations is usually optional but it is interesting to note the increasing interest in welding subjects and the growing extent to which they are being selected for research problems. As an example, in the Department of Mechanical Engineering during the past year the following are a few of the thesis investigations which have been presented in partial fulfillment of the requirements for the batchelor's degree:

"Investigation of Residual Stress, Shrinkage and Distortion in a Welded Structure."

"The Welding and Repair of Manganese Steel Castings in Railroads."

"The Spot Welding of Thin Duralumin Sheets."

"The Spot Welding of $^1/_4$-In. Nickel Steel Plates."

"Flame Cutting of Steel and Its Effect on Welding."

"A Study of the Technique of Spot Welding Thin Stainless Steel."

"The Impact Resistance of Butt and Flash Welds."

Many other theses in welding have been presented to other departments but it is interesting to note the diversification of selection in the above subjects. It is believed that as more welding is introduced to the curriculum more voluntary work will correspondingly be elected.

Size and Spacing of Spot Welds

By R. L. BRIGGS†

IF A representative group of resistance-welding engineers were asked to recommend what they considered to be the best ratio of die point diameter to stock thickness in spot welding there would probably be as many different recommendations as there were men in the group. Each man might have intelligent reasons for his choice. That a difference of opinion exists, however, is likely due to the fact that no careful study has been made of this peculiarly essential factor in spot welding.

This article concerns itself with the size and the spacing of circular spot welds. Subsequent discussion of the subject will be based on practical considerations, theoretical analysis and experimental data. It is hoped that this material will serve as a useful contribution to the art of resistance welding.

Present Practice

Modern spot-welding practice calls for the spacing and use of spots of such size as will prove practical and satisfactory. The size of the spots is materially influenced by the thickness and properties of the material to be welded, by the capabilities of the spot-welding equipment being utilized and by the finished appearance of the weld which is desired.

Practical considerations prohibit the use of a die point having a diameter of 100 times the thickness of the stock being welded, despite the long life of the die point which such a choice would produce. Heavy mechanical pressures and large electrical transformer capacities would be required. There also exists the difficulty of bringing the entire surface of the die point in contact with the stock. Figure 1 shows such a weld.

Similarly, the use of a die point having a diameter of one-tenth the stock thickness is impractical, despite the low mechanical and electrical capacities which could be employed. Such a point would have a short useful life and require frequent shaping. It would mar or indent the surface of the stock. The weld would lack suitable strength. Figure 2 shows such a weld.

Somewhere between these extremes of die point diameter ratios lies an ideal relationship to the stock thickness. It will be one where a reasonable relationship exists between the transformer requirements and the strength of the weld. It will be one giving a satisfactory die point life. It will be one where the strength of the spot weld it produces will compare favorably with riveting requirements.

† Research Engineer, Thompson-Gibbs Electric Welding Company.

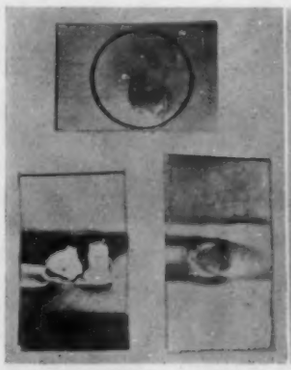


Fig. 1

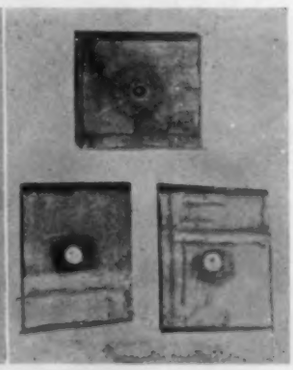


Fig. 2

Theoretical Considerations

(A) *Power Requirements*

It can be demonstrated by mathematical considerations of the heat and heat losses during the production of a spot weld that the electrical power required at the

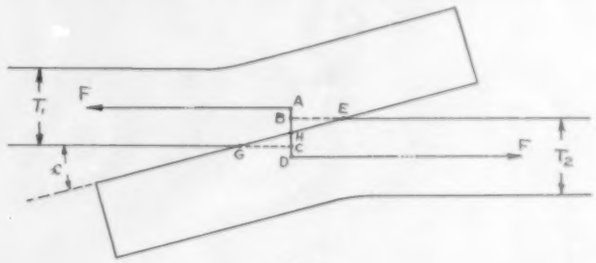


Fig. 3

weld is given by the formula

$$W = K_1\left[K_2\frac{Td^2}{t} + K_3T + K_4\frac{d^2}{T}\right] \text{ watts}$$

where T is the stock thickness; d is the diameter of the weld; K_1 is a function of the fusion temperature of the stock; K_2 is a function of the electrical, thermal and physical properties of the stock; K_3 is a function of the thermal properties of the stock; and K_4 is a function of the thermal properties of the dies. This formula can be written

$$W = C_1\frac{Td^2}{t} + C_2T + C_3\frac{d^2}{T}$$

The first term measures the power needed in the stock to get fusion, the second term the power lost by heat conducted into the stock material surrounding the spot and the last term the power lost by heat conducted into the die points. The welding time is represented in the formula by t.

The ratio of the power W to the spot diameter d is given by the formula

$$\frac{W}{d} = d\left(\frac{C_1T}{t} + \frac{C_3}{T}\right) + \frac{C_2T}{d}$$

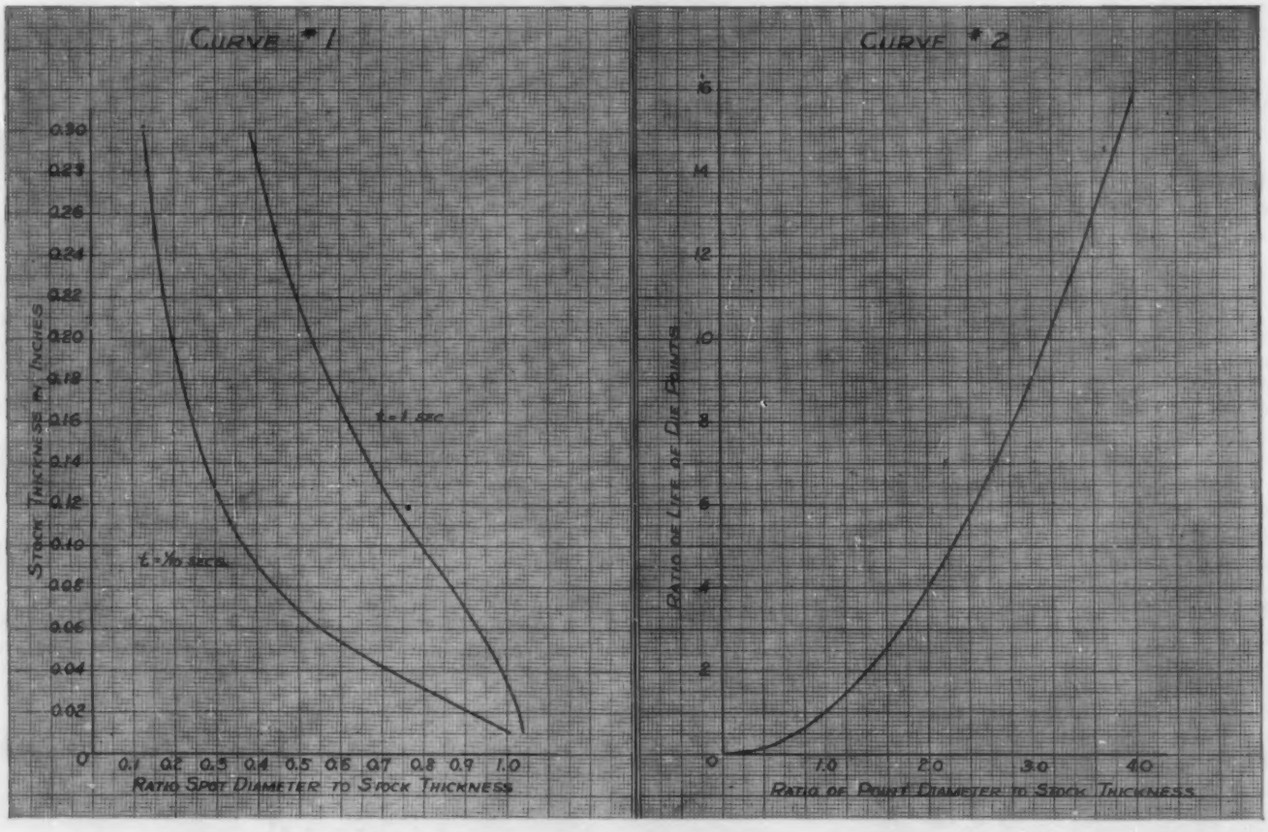
By differentiating with respect to d, and equating the differential to zero, we may solve for the most favorable ratio of W to d. This results in the formula

$$d = T\sqrt{\frac{C_2t}{C_1T^2 + C_3t}}$$

If we insert values of C_1, C_2 and C_3 for steel it can be shown that for values of T where the term C_1T^2 becomes negligible (values below 0.020 in.) d equals T for the most favorable ratio of W to d. For the larger values of T the ratio d/T becomes less than unity particularly when very short welding times are used. (See Curve 1.)

(*B*) *Die Point Life*

By the life of a die point is meant the period during which it can be used to make spot welds of approximately uniform size. It is well known that the continued use of a die point at pressures in excess of the ultimate compressive strength of the die point material will cause the material to "flow." This action results in the continual enlarging of the die point area. When this area has increased beyond a reasonable limit the die point must be "dressed" or reshaped. The useful



period between successive dressings is termed the life of the die point.

The welding pressures used in spot welding a given thickness of stock vary over wide ranges. If expressed in terms of lb. per sq. in. of die point contact area, the compressive pressures will range from 15,000 to 100,000 lb. per sq. in. In this respect it is interesting to note the comparative compressive strengths of some of the standard spot-welding die point materials: Hard drawn copper, 58,000; Electroloy, 80,000; Elkaloy, 80,000; Elkonite, 208,000.

By a simple physical analysis it can be demonstrated that the life of a die point is expressed by the formula

$$N = C\frac{D^2}{Pf\left(\frac{1}{S_c}\right)}$$

where C is a constant, D is the die point contact area diameter, P is the welding pressure in lb. per sq. in. and $f(1/S_c)$ is a function of the reciprocal of the compressive strength of the die point material. Several interesting deductions may be obtained from this equation. It should be noted, however, that for the same die point pressures in lb. per unit area, other conditions being equal, the die point life varies as the square of the point diameter.

There are three ways of prolonging the life of the die point. First, we may reduce the welding pressure in lb. per unit area. While this is a possible method and allows the use of reduced electrical capacities, it is not always a practical solution. It is often necessary to overcome "dishing" or an uneven surface condition in the stock by using relatively large die point pressures in order to bring the pieces of stock together at the point to be welded. The second method of prolonging the life of the point is to increase the point diameter. This leads to the necessity of using higher electrical capacity and larger mechanical welding pressures. It is a method often adopted by industry, but has the disadvantage of producing unnecessarily large spots and requiring heavier welding equipment. The third method of increasing the life is to increase the toughness of the die points by using a material of greater compressive strength characteristics. While this method sometimes leads to difficulties due to the heating of the points, these difficulties can be largely overcome by efficient die point design. From a technical point of view this is much the best method of increasing the life of the points.

(*C*) *Strength of Spot Welds*

In this section a study will be made of the strength of circular spot welds and to develop suitable formulae to allow the calculation of the strength of any size

weld in any type of stock. An application of the use of these formulae for a particular type of stock will be given together with suitable curves showing the useful data. A practical analysis of this data will be given.

The forces on a spot weld under a tensile pull of F lb. are of three types. First, there is a bending moment which tends to "tip" the weld through an angle α. Second, there is a shearing force F_s which equals F Cos α. Third, there is a tensile force F_t which equals F Sin α. Except under very unusual circumstances, this latter force is so small that it can be neglected in the analysis. Reference is made to Fig. 3 in the following analyses.

The bending moment is the product of the force F and the moment arm AD. Let $d = GE$, the diameter of the welded section. Let T_1 and T_2 be the thicknesses of the two pieces of stock being welded. Let α be the angle of tipping. Then

$$AD = AC - CH + BD - BH$$
$$= AC + BD - CH - BH$$

but $AC + BD = {}^1/_2(T_1 + T_2)$

and $CH = BH = {}^1/_2\, d \text{ Sin } \alpha$

hence $AD = {}^1/_2(T_1 + T_2) - d \text{ Sin } \alpha$

Hence the bending moment is

$$\text{B. M.} = \frac{F}{2}(T_1 + T_2) - Fd \text{ Sin } \alpha$$

The tipping angle α may be determined through the use of flexure theory. The bending moment in both strips is identical and the angle through which each strip bends is the same, even if the strips differ in thickness. It can be shown that

$$\beta = \frac{\text{Tan } \alpha}{1 - k \text{ Sin } \alpha} \qquad \text{Equation 1}$$

where $k = \dfrac{2d}{T_1 + T_2}$

and $\beta = \dfrac{3F(T_1 + T_2)}{2Ed^3}$

E is the modulus of elasticity of the material in the material in the strips. β may be calculated from the dimensions and physical properties of the material. By the use of suitable curves of $\dfrac{\text{Tan } \alpha}{1 - k \text{ Sin } \alpha}$ plotting α in terms of β, we may solve for the tipping angle when β is known. See Curve 4 for the plot of such data.

The shearing force on the spot weld is $F_s = F$ Cos α. If s_s represents the shearing stress in the welded section under this load then

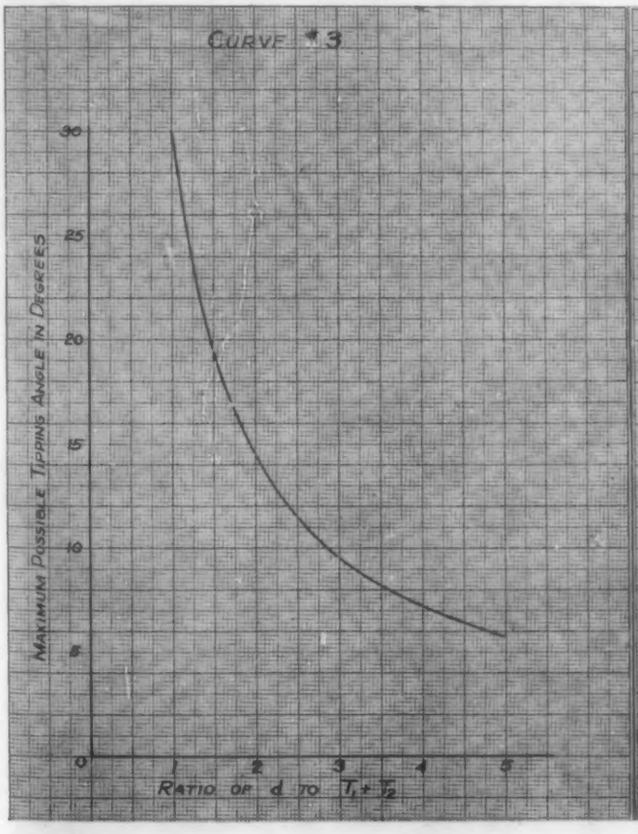
$$S_s = \frac{4\, F \text{ Cos } \alpha}{\pi d^2} \qquad \text{Equation 2}$$

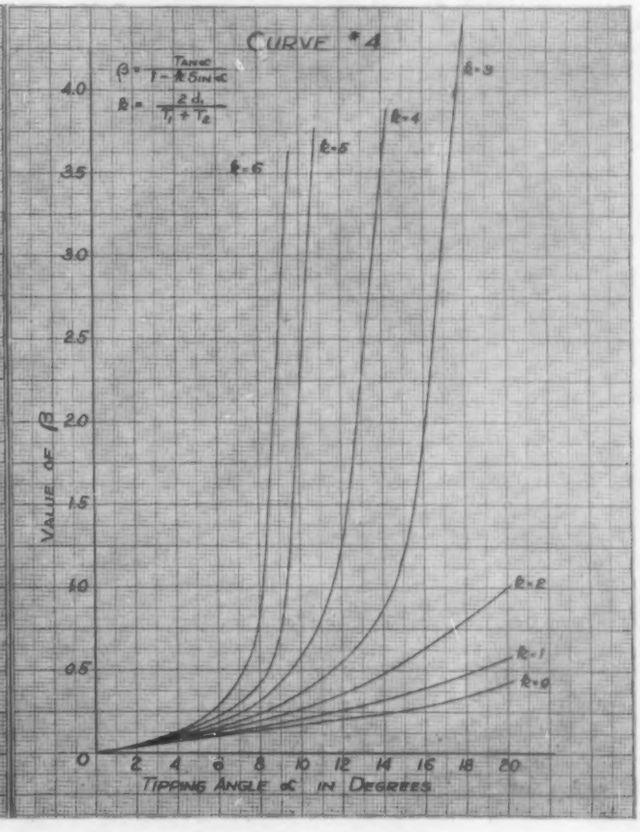
(*D*) *The Spot Weld at Rupture*

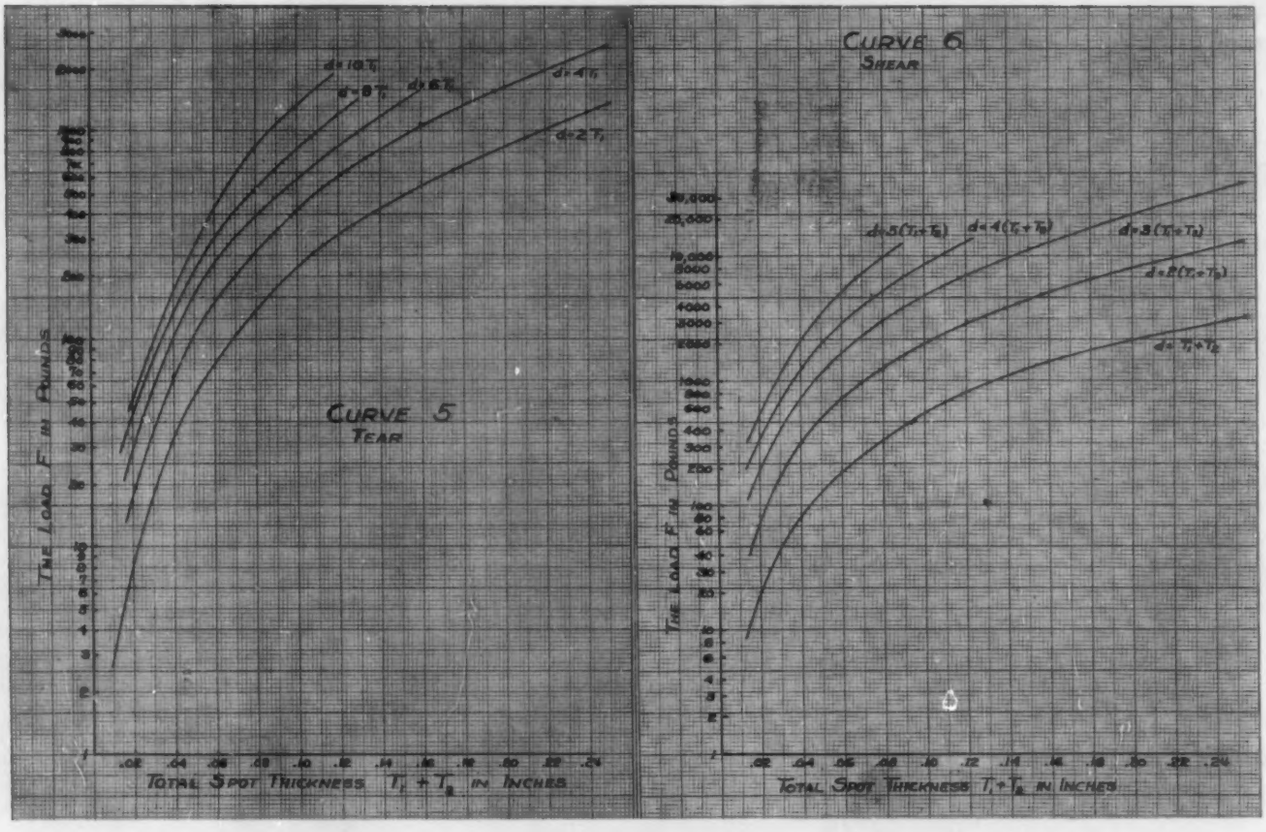
A spot weld may rupture in one of two ways. The weld may tear out around the fused section, a process known as pulling out a "plug," or it may shear the fused section. The rupture may be caused by a linear or straight line load, or by a torque or twisting load. This latter type of loading is rarely met, and should not be allowed on spot welds. For this reason the following paragraphs will be devoted to a study of the rupture value of the linear load only, as is illustrated in Fig. 3.

When rupture occurs by the spot tearing out around the welded section it is evident that just prior to the rupture the points of maximum fiber stress are at G and E. It is also evident that the weld may tip to an angle α_m without rupturing. At this angle the load forces F are in line with each other. It can be shown that

$$\text{Sin } \alpha_m = \frac{T_1 + T_2}{2d} \qquad \text{(See Curve 3.)}$$







The weld may, however, rupture at some angle less than α_m.

The fiber stress at points G and E may be determined through the use of proper flexure analysis. Let us assume that the portion of the stock, perpendicular to the line of the forces F, along which the fiber stress varies uniformly in the perpendicular plane and in which section the maximum fiber stress occurs, may be represented by a surface of height T_1 or T_2 and of a width equal to one quarter of the circumference of the welded section. The neutral axis of this surface is at its center of gravity. The maximum fiber stress can now be written

$$f_m = \text{B. M.} \frac{T_1}{2I} \quad \text{or} \quad f_m = \text{B. M.} \frac{T_2}{2I}$$

where the B. M. $= \frac{F}{2}(T_1 + T_2) - Fd \text{ Sin } \alpha$

and $I = \frac{\pi d\, T_1^3}{12}$ or $I = \frac{\pi d T_2^3}{12}$

If we let T_1 be the thinner of the two pieces of stock then the maximum fiber stress can be written

$$f_m = \frac{6F}{\pi d T_1^2}\left[\frac{T_1 + T_2}{2} - d \text{ Sin } \alpha\right] \quad \text{Equation 3}$$

When the elastic limit of the material has been reached and exceeded the weld will tip through an angle α_m. In such cases the bending moment becomes zero and the maximum fiber stress is given by the formula

$$f_m^1 = \frac{4F}{\pi d T_1}$$

Rupture may occur through the shearing of the welded section. If s_{sm} is the maximum allowable shearing stress in the welded material and the weld tips through an angle α, then the resistance of the weld to shear is given by the formula

$$F = \frac{\pi d^2 S_{sm}}{4 \text{ Cos } \alpha} \quad \text{Equation 4}$$

(E) *The Tipping Angle at Rupture*

We have developed three formulae in the previous sections which express the relationship between the force F and the angle α. Rewriting and simplifying these formulae, we obtain

$$F = \frac{2Ed^3}{3(T_1 + T_2)} \cdot \frac{\text{Tan } \alpha}{1 - \frac{2d}{T_1 + T_2} \text{ Sin } \alpha} \quad \text{Equation 1}$$

$$F = \frac{\pi d^2 S_s}{4 \text{ Cos } \alpha} \quad \text{Equation 2}$$

$$F = \frac{\pi d T_1^2 S_t}{3(T_1 + T_2) - 6d \text{ Sin } \alpha} \quad \text{Equation 3}$$

If s_s and s_t become the ultimate allowable shear stress and tensile stress then the Equations 2 and 3 express conditions at shearing or tearing rupture. We may hence solve for the tipping angle at which shearing or tearing takes place by substituting either Equation 2 or Equation 3 in Equation 1, and solving for a function of the angle.

The angle α at shear may be determined by substituting Equation 2 in Equation 1 and solving. We obtain the formula

$$\text{Sin } \alpha = \frac{T_1 + T_2}{2d} \cdot \frac{3\pi S_s}{4E + 3\pi S_s} \quad \text{Equation 5}$$

The angle α at tearing may be determined by sub-

stituting Equation 3 in Equation 1 and solving. We obtain the formula

$$\text{Tan } \alpha = \left(\frac{T_1}{d}\right)^2 \frac{\pi S_t}{2E} \qquad \text{Equation 6}$$

It should be noted that Equations 5 and 6 give the angle of tipping at which the ultimate shear and tensile stress of the material is exceeded. In the case of soft materials such as copper the material will stretch under continued application of the load causing these stresses until the tipping angle reaches its maximum value, the weld not having previously broken. The equation for this angle has been developed, and the rupturing force to shear the weld may be calculated by using Equation 2. The rupturing force to tear the weld is given by the formula

$$F = \frac{\pi d T_1 S_t}{4}$$

(F) Spacing of Spot Welds

When a single row of spot welds is asked to carry a given load a knowledge of the probable ultimate strength of the individual welds is necessary. The strength of a single spot has been analyzed in the preceding sections. Through the use of a suitable safety factor and the knowledge of the required strength, the number of spots theoretically required in a single line can be quickly calculated. It should be carefully noted, however, that while spot welding differs from riveting inasmuch as the welds may be placed quite close together, welds which are not appreciably separated will not be uniform in characteristics. In the case of two welds made close together with the same adjustment of the welder for each weld, the first weld made will be measurably stronger. Allowances should be made for this feature in certain types of work, and the practical method is to use more energy in making the second and subsequent welds.

When small diameter spots are used in welding thin stock there is a real advantage in using two rows of spots, since the second row of spots materially reduces the tipping effect under load. This increases the effective strength of each weld.

(G) Application of the Formulae

The practical use to which these theoretical formulae can be put is best illustrated by a specific example. Let us determine the best ratio of the spot diameter to the thickness of stock when welding steel. It should be carefully noted that the formulae are used to determine the effect of this ratio on (*a*) the electrical capacity requirements, (*b*) the die point life and (*c*) the strength of the spot weld. From these studies there can be an intelligent choice made of the best ratio of the spot diameter for any given stock thickness.

What will be the effect of the spot diameter on the electrical capacity? We have developed a formula for the spot diameter which gives the most favorable ratio of the capacity to the diameter. It is

$$d = T\sqrt{\frac{C_2 t}{C_1 T^2 + C_3 t}}$$

Now $C_1 = 26.3(T_d - T_r)c\rho$, $C_2 = 26.3(T_d - T_r)k_w$ and $C_3 = 3.29(T_d - T_r)K_d$ where T_d is the fusion temperature of steel; T_r is the room temperature; c is the specific heat of steel; ρ is the density of steel; k_w is the thermal conductivity of steel; and K_d is the thermal conductivity of the dies, all in c.g.s. units. Substituting the various values for steel and the dies (copper) in the formula, and transferring to English units, we obtain the formula

$$d = T\sqrt{\frac{4.73t}{307T^2 + 4.34t}}$$

This formula is plotted in Curve 1. It shows the values of d as a fraction of T, plotted against T, for the best capacity ratio. The curve has been drawn for two values of the time t in order that the effect of this factor on the ratio may be observed.

What will be the effect of the die point diameter on its life? Curve 2 shows the life factor of the die point plotted against its diameter D. It offers a comparative value by which relative life may be estimated, using a value of unity life for a die point equal to the stock thickness in diameter. It should be noted that this curve is based on the use of a constant welding pressure per unit area of the die point.

What is the effect of the spot diameter on the ultimate strength of the weld? By solving Equation 6 to obtain the angle at which tearing takes place and substituting it in Equation 3 we may solve for the force or load at which tearing will occur. The values of this load are plotted in Curve 5 for different ratios of the spot diameter to the stock thickness. By solving Equation 5 to obtain the angle at which shearing takes place and substituting it in Equation 2 we may solve for the load at which shearing will occur. The values of this load are plotted in Curve 6 for different ratios of the spot diameter to the total thickness of the two pieces of welded stock. Both of these curves were calculated using the following physical values for steel: modulus of elasticity 29,000,000; maximum tensile stress 80,000; maximum shear stress 65,000. It was also assumed that both pieces of stock being welded were of equal thickness.

It should be noted that these curves give the calculated breaking or rupture load to shear or tear out the spot. For a given thickness and diameter of spot the calculated type of rupture will be dependent upon which of these two loads is the smaller. Also it should be particularly noted that the tearing load is calculated on the basis of being that load which exceeds the rupture stress in the material at the corners of the weld designated in Fig. 3 as points G and E. The weld will stand overloading above this value before actual rupture occurs, but the elastic limit of the material is exceeded by this overloading and distortion occurs until rupture finally takes place.

(H) Summing Up the Data

As has been pointed out in the preceding paragraphs, Curve 1 gives the best die point diameter ratio to the stock thickness from the standpoint of electrical capacity requirements. Curve 2 gives the life ratio for different ratios of die point diameters to the stock thickness. Curves 5 and 6 give the strengths of spot welds for different spot diameter ratios to the stock thickness. All these curves were calculated for steel. From this data the engineer may make an intelligent choice of the best size of die point to use on a given thickness of steel stock having physical characteristics as used in the previous calculations. If *strength* is most important and his electrical capacity is sufficiently large, Curves 5 and 6 will most strongly influence his choice of die point sizes. Some observations on this point are certainly pertinent, however. When $T_1 + T_2$ is less than 0.060 in., capacity limitations should not be allowed to become a serious factor, except in the cases of certain

portable spot welding set-ups. A ratio of die point diameter to the total thickness of 3 and 4 is not at all unreasonable. When, however, $T_1 + T_2$ exceeds 0.200 in., electrical capacity becomes an important factor for most installations, Curve 1 becomes influential, and ratios of die point diameters to total thicknesses of $^3/_4$ and 1 are perfectly feasible.

For the average set-up a typical choice for the size of spots might be as follows:

Stock Thickness	Ratio of d to T_1
–0.020	6–5
0.020–0.030	5–4
0.030–0.050	4–3
0.050–0.080	3–2
0.080–0.125	2–1
0.125–0.250	$1–^3/_4$

Curves 3 and 4 are supplied to facilitate calculating the stresses in a given spot produced by a known load and in determining the maximum tipping angle which a spot weld in soft material might take.

(*I*) *Checking against Experimental Data*

Experimental tests of the strength of spot welds in steel stock having the physical properties as used in the previous calculations indicate that the calculations are conservative in their prediction of rupture loads.

Taking an average of the experimental results and checking them against the calculated rupture values, calling the calculated rupture values 100, it was found that the following relationship between the experimental data and the calculated data existed:

Calculated rupture load	100
Load at which distortion was evident	150
Actual rupture load	250
Type of rupture	As calculated

Conclusions

This material is presented in the hope that it will be of assistance to the engineer who has a real interest in the problem of the best spot size for his particular job. No attempt has been made to lay down any rigid rules regarding the size or spacing of the welds. Rather an endeavor has been made to present the various factors which influence the size of the spot weld in such a manner as will make it possible for an intelligent choice of the proper size to be made. For obvious reasons the development of the various formulae was not presented. It is hoped, however, that some of the more interesting derivations can be presented at some future time. A typical application of the formulae for the welding of steel was given to illustrate the practical use to which the material might be put, and curves were given plotting the essential data. Three curves, Curve 1, 5 and 6 should not be used in any discussion of welds in a material other than that for which they were calculated. Curve 1 will not vary materially for any of the other ferrous materials, but will have different characteristics for the non-ferrous metals. Curves 5 and 6, or such individual points as the engineer may be interested in, must be calculated for each individual metal.

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(*Continued on page 32*)

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

Resistance Welding Number

At the request of Mr. M. Poplavko, President of the U. S. S. R. Welding Society, this issue has been devoted largely to Resistance Welding papers. The papers will form the basis for discussion at a conference to be held in Moscow during the early part of 1935. It is a pleasure for the AMERICAN WELDING SOCIETY to cooperate with its sister society in Russia in this type of work. Additional Resistance Welding papers will be published in the next issue of the Journal.

Prosaic but Promising

(Taken from Oct. 11, 1934, issue Engineering News Record.)

A more prosaic subject for investigation than shelf angles can hardly be imagined. Yet the results of the first year's tests by the structural steel welding committee of the American Bureau of Welding are instructive and in some respects significant. The program included load tests on full-size welded specimens and connections as well as a photoelastic study of half-size angles. If some of the results might have been predicted, such as the presence of tension on the top of the side welds in addition to the shear, there was nevertheless obtained a qualitative picture of the dominating importance of this tension, which promises to point the way to a rational theory of design. It is also important to know that concentrated loads are no more severe than, and indeed act quite similar to, loads distributed along the full length of the outstanding leg. While this has been assumed to be the case for riveted shelf angles, with rivets on the center line of the vertical leg, it was not evident that it would hold when the connection was made by welds along the edges only.

From an economy standpoint it is useful to know that welds longer than are dictated by requirements of the vertical shear contribute no additional strength and constitute so much waste metal, also that increasing the size of the weld does not give a proportionate gain in weld strength. What is probably the most significant result of the investigation came from the photoelastic studies, which demonstrated quite conclusively the advantage of long-radius fillets on shelf angles. Such fillets not only give the outstanding leg increased bending resistance, they also decrease the controlling compressive stress materially at a point where it is a maximum, namely, across the fillet at an angle of 20 to 30 deg. with the vertical. This result is quite as important to riveted as to welded construction. The structural steel welding committee deserves commendation for continuing its practice of taking no riveted precedents for granted where welding is concerned. This trait of universal curiosity not only may lead to complete knowledge of welded shelf angles, but conceivably it might develop a more efficient new detail that would eliminate seat angles entirely. In such an event the full promise of the present investigation would indeed be achieved.

Alloys of Iron and Tungsten

By J. L. GREGG

This book offers to the metallurgist, engineer, foundryman or steel maker interested in alloys, steels and cast irons, a complete critical appraisal of the literature and other sources of information on the manufacture, properties and uses of steels containing tungsten as an alloy, including high-speed and tungsten magnet steels.

To the manufacturer and user of tools, it offers a concise but complete discussion of the history, manufacture, mechanical properties and cutting performance of tool steels containing tungsten as an important alloy, including high-speed and fast-finishing steels.

To the research metallurgist, it offers a critical summary and appraisal of all past research work on the binary alloys of iron and tungsten, and on ternary and more complex alloy systems containing tungsten as an important component.

The steel-works metallurgists, superintendent, melter, foundryman and engineer will find in it all essential data on steels and cast irons containing tungsten. There is information on the ores and their reduction, on the manufacture, structure, properties and uses of tungsten steels including magnet and die steels, on tungsten corrosion and heat-resisting alloys, and a concise but complete discussion of the manufacture, mechanical properties, cutting performance and uses of high-speed and other tungsten tool steels.

New Welding Exhibit for Museum of Science and Industry

Announcement is made by Mr. O. T. Kreusser, Director of the Museum of Science and Industry in Chicago, that complete equipment, including material handling hoist for a permanent exhibit of industrial welding, has been presented to the institution by the Harnischfeger Corporation of Milwaukee, manufacturers of P&H-Hansen Arc Welders.

This exhibit is of unusual interest because of the rapidly increasing use of arc welding in practically all lines of industry. The exhibit itself is an ingenious one, for with the demonstrations carried on behind a special colored glass, visitors are able to see at close range the technique employed in various types of welding without blinding glare.

The Museum of Science and Industry in Chicago is the only institution of its kind in the United States with a permanent arc-welding demonstration.

EMPLOYMENT SERVICE BULLETIN

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SECTION ACTIVITIES

BOSTON

A regular meeting of this Section will be held on Friday evening, November 16, 1934, in the rooms of the Engineering Societies of New England, 715 Tremont Temple, Boston, at 7:30 P.M.

The major part of the program will consist of motion pictures, and the following subjects are included in the program.

"A Century of Progress"—the high lights of the World's Fair at Chicago.

Film dramatization of oxyacetylene welding, including an animated drawing showing the fundamentals of the process. Action occurring inside of regulators and blow pipes when in operation.

Applications of welding and cutting in many industries.

CHICAGO

A very interesting and important meeting was held on Friday, October 26th as the opening meeting of the winter season. Mr. George Horton, President of the Chicago Bridge and Iron Works, gave an illustrated talk on field-welded tanks. Mr. Horton is the designer of the Hortonsphere and other forms of storage tanks.

Mr. A. E. Gibson, Chairman of the Cleveland Section, Vice-President of The Wellman Engineering Company, spoke on the application of welding to heavy machinery such as car dumpers, bridges, steel mill machinery, gas producers and so forth.

CLEVELAND

The following is the program for the November and December meetings of the Cleveland Section.

November 14th—Speaker will be Mr. A. S. Douglass, Construction Engineer of The Detroit Edison Company. His address will be on "The Welding of the High Pressure, High Temperature Steam Station Piping." The talk will be illustrated by many lantern slides of actual welding operations.

December 12th—Speaker will be Mr. J. W. Owens, Director, National Weld Testing Bureau, who will talk on the subject "Weld Testing and Supervision." This address will also be illustrated.

DETROIT

A joint meeting of the Detroit Sections, A. W. S. and A. S. M. E. was held October 16th at the Hotel Fort Shelby, Detroit. Over three hundred and twenty-five members of the Societies and their guests attended.

The speakers were Mr. Edward G. Budd, President, and Mr. Joseph W. Winlock, Metallurgist, the Edward G. Budd Manufacturing Co., Philadelphia.

Mr. Winlock's subject was "Shot Welding of Stainless Steel as Applied to the Burlington Zephyr." After briefly tracing the history of stainless steel, the speaker explained the composition and uses of the different kinds, stressing particularly the 18-8 type. He discussed the occurrence of inter-granular corrosion and the studies that have been made to develop a method of welding which avoids causing such corrosion. The careful timing and selection of current values required for a given resistance were clearly illustrated by slides. Mr. Winlock's paper was very instructive and was presented in the clearest manner.

Mr. Edward G. Budd described the trial runs of the Zephyr, giving many sidelights on the construction, equipment and performance of the famous train which were of absorbing interest. He then showed a two-reel moving picture depicting the spectacular run of the Zephyr from Denver to Chicago May 26, 1934, a run which covered 1017 miles in 13 hours without a single stop. Mr. Budd was a passenger on the train that day and gave many interesting comments on the trip.

There followed a rapid fire of questions, both general and technical, which were clearly answered by both Mr. Budd and Mr. Winlock.

On account of interfering meeting dates of other technical societies, the A. W. S. will not have a Detroit meeting in November. Arrangements are under way for another joint meeting to be held during the first week of December.

NEW YORK

A joint meeting of the New York Section, AMERICAN WELDING SOCIETY, with the Machine Shop Practice Division of the American Society of Mechanical Engineers will be held on November 19th. The subject of the meeting will be "Welding Versus Castings." It will be devoted to a discussion of relative merits of welded versus cast frames, bases and other structural parts of machines and machinery. Mr. Everett Chapman of Lukenweld. Inc., will talk on "Welding Versus Castings"; Mr. E. W. P. Smith of the Lincoln Electric Company will talk on "Design Procedure for Converting from Cast Iron to Steel" and Mr. R. H. Longbottom of the Dodge Steel Company, will present an address on "Casting Versus Welding."

An unusual meeting is scheduled for December 11th featuring "Flame Cutting of Special Steels," by Bradley Stoughton of Lehigh University, and "Requirements of the A.S.M.E. Unfired Pressure Vessel Code," by W. D. Halsey, Hartford Steam Boiler Insp. & Ins. Co.

PITTSBURGH

"Profits of Progress" an industrial drama in four acts was presented on November 14th at the Davis Theatre. This play was presented as part of the Thirty-Fifth Annual Convention of the International Acetylene Association. The Pittsburgh Section of the AMERICAN WELDING SOCIETY cooperated in this meeting.

Current Welding Literature

(*Continued from page 30*)

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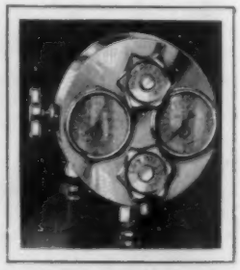

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